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DETECTION AND IDENTIFICATION OF MARINE MAMMALS IN PASSIVE ACOUSTIC RECORDINGS FROM SCORE USING A VISUAL PROCESSING APPROACH ESTABLISHED FOR HARP DATA

By

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June 2012

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LIST OF ACRONYMS AND ABBREVIATIONS

ARP	Acoustic Recording Package
ASW	Anti-submarine Warfare
FFT	Fast-Fourier Transform
GUI	Graphical User Interface
HARP	High-frequency Acoustic Recording Package
ICI	Interclick Interval
LTSA	Long-Term Spectral Averages
NPS-DAS	Naval Postgraduate School Data Acquisition System
PAM	Passive Acoustic Monitoring
PWSD	Pacific White-sided Dolphin
ROC	Range Operation Center
SCORE	Southern California Offshore Range
SIO	Scripps Institution of Oceanography
SOAR	Southern California Anti-Submarine Warfare Range

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I. INTRODUCTION

For many years, marine biologists have had to face the challenges of studying marine mammals in their natural environments, from battling bad weather to dealing with the limitations of visual-based methods to detect and identify marine mammals. These visual-based methods can also be manpower intensive and are as effective as the weather and normal activities of the marine mammals allow.

Due to the advances in technology, there is an increasing interest in the biology community about the usefulness of passive acoustic monitoring (PAM) to study marine mammals in their natural environments (Zimmer 2011) without having to worry about bad weather, low visibility or impeding their natural behaviors. The use of PAM not only complements visual-based detection but may be a more effective method in the long-term.

The U.S. Navy conducts environmental assessments to help minimize negative impacts to the environment from naval activities while maintaining fleet readiness. These environmental assessments are made in part to determine the potential impacts to marine mammals from naval operations. One of the obstacles the Navy must overcome in preparing for these assessments is the lack of information on marine mammals and their behaviors (Hildebrand 2005).

A particular concern in the recent years is trying to understand the effects of acoustic energy from sonar on marine mammals, especially on beaked whales. Until recently, marine mammal assessments have relied on visual surveys from surface and air. The difficulty and cost of these visual surveys and the low numbers of sightings make them impractical (Hildebrand 2005).

The technology of passive acoustics has recently been advanced to allow these methods. The High-frequency Acoustic Recording Package (HARP) developed by Scripps Institution of Oceanography (SIO) is an example currently in use in many areas of the world. The U.S. Navy also has several instrumented training ranges that have potential to be used for PAM purposes. At the Southern California Offshore Range

(SCORE), the Naval Postgraduate School (NPS) has installed a digital recording system that receives data through multiple range hydrophones. PAM systems tend to generate very large raw data sets due to the wide frequency bandwidth of interest, length of recording and number of hydrophone involved. As a consequence, efficient methods are required to analyze the data in a timely manner.

SIO has developed a visual processing approach for use with HARP data sets. NPS has successfully applied this technique to analyze PAM data sets collected on HARPs deployed off Point Sur, California. We feel the methodology has potential to be applied to the NPS data sets collected at SCORE (hereafter referred to as "SCORE data"), however, because of differences in recording system characteristics, it is anticipated that modifications to the methodology will be needed.

This thesis uses HARP and SCORE passive acoustic recordings collected simultaneously and in close proximity to one another in the San Nicolas Basin to examine the feasibility of applying the protocols used for HARP data analysis to SCORE data. By using data from the same locale and timeframe, it is expected that vocalizations from the same groups of animals will be encountered on both systems allowing a direct comparison of how their identifying features are represented in the visual processing to the analyst.

There are several differences to consider at the outset of this research. First, SCORE data were recorded through multiple hydrophones that were not designed for marine mammal monitoring. Second, HARP and SCORE instruments collect data over different frequency bandwidths. Third, the data were recorded using different sampling frequencies. HARP used 200 kHz for both June and November 2008 whereas SCORE used 96 kHz for June and 80 kHz for November. Lastly, the quality of the information that can be potentially obtained is dependent on the amount and type of animals that were in the area during the recording period.

The scope of this thesis is limited to identifying acoustic features of the data collected on the HARP and three nearby SCORE hydrophones obtained in June and

November 2008 and compiling a list of comparable features that can potentially be used to identify marine mammals and their behaviors based on vocalization.

Even though HARPs can record vocalizations of mysticetes and odontocetes, i.e., both low- and high-frequency vocalizations, we limited our study to vocalizations of odontocetes species due to the limited frequency response of the SCORE hydrophones which have a bandwidth of approximately 8 to 40 kHz.

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II. BACKGROUND

Since mankind first began to sail the open ocean, we have been intrigued by the animals that inhabit these waters. In present times, some of the mystery that surrounded marine mammals has been answered but our fascination with them and their behaviors continues. Modern day scientists remain committed to their conservation and continue to pioneer new ways to observe and record their natural behaviors.

Research in the past has been limited to observations of surface behavior (Zimmer 2011). These traditional methods for cetaceans detect only a fraction of the animals due to fact that observers only have a short amount of time to detect them, when they are at the surface, and visual surveys can only be conducted during daylight hours and in relatively good weather conditions (Mellinger et al. 2007). Visual detection is very limiting, not only because the ocean is very expansive, but because many of marine mammal’s natural behaviors occur underwater and are based on an intricate acoustic language.

In the recent years, the advances of underwater hydrophone and data processing technology have allowed the use of PAM methods to study cetaceans such as whales, dolphins and porpoises. There is a growing recognition in the marine biology community that many species of interest are easier to hear than to see (Zimmer 2011). PAM is also very flexible in the ways in which it can be accomplished: towed behind a ship, affixed to an ocean glider or other mobile platform, or permanently mounted to the seabed (see Mellinger et al. 2007).

PAM not only complements visual observations but allows scientists to study cetacean behaviors while submerged. In joint visual-acoustic surveys, acoustic methods have detected one to ten times as many cetacean groups as visual ones (McDonald and Moore 2002). There are two types of PAM equipment widely used: cabled hydrophones, such as those found at SCORE, and autonomous recorders, such as HARP.

In San Nicholas Basin, a diverse array of marine mammals can be found to include odontocetes (toothed whales), mysticetes (baleen whales), and pinnipeds

(walruses and seals) (Hildebrand et al. 2011). We anticipated detections of odontocetes that vocalize in the high-frequency range: 8 to 100 kHz. Odontocetes typically found in San Nicolas Basin include Cuvier's beaked whales (*Ziphius cavirostris*), sperm whales (*Physeter macrocephalus*), and different delphinid species, including killer whales (*Orcinus orca*), Risso's dolphins (*Grampus griseus*), and Pacific-white sided dolphins (*Lagenorhynchus obliquidens*) (Hildebrand et al. 2011). Below, we discuss the population, ecology, behavior and vocalization characteristics of some toothed whales, which are year round or seasonal residents of the Southern California Bight.

A. CUVIER'S BEAKED WHALES (*ZIPHIUS CAVIROSTRIS*)

Cuvier's beaked whale is the most common species of beaked whale found in the Southern California area (Hildebrand et al. 2011). It is estimated that there are approximately 1,200 Cuvier's beaked whales along the west coast of the continental United States (Carretta et al. 2007).

Cuvier's beaked whales normally inhabit the waters over the continental slope and deep oceanic water, usually being sighted in waters that are deeper than 200 m (Jefferson et al. 2008) and are routinely recorded in depths of 1000 m or more (DON 2008).

Cuvier's beaked whales are long, deep divers and have been recorded conducting dives that last for almost 1.5 hours and at depths of almost 2 km (Rommel et al. 2006). It was once thought that Cuvier's beaked whales only feed at the ocean bottom, but recent studies have found that they may also feed at mid water levels (DON 2008).

Cuvier's beaked whales are found in small groups of two to seven, but it is not uncommon to see them alone or with a group of dolphins (Jefferson et al. 2007). There is no known calving season. Although not seen every month, beaked whales are found randomly throughout the year in this area (Dohl 1980).

Cuvier's beaked whales produce broadband echolocation clicks that are very distinct from those of any other species and last about 200 µs. Their clicks span over a frequency range of 20 to 60+ kHz, with the dominant frequency near 40 kHz. Beaked

whale clicks have a very distinct upsweep in frequency. This upsweep occurs over a 0.15 ms interval. Their clicks also have a very specific inter-click interval (ICI) of 0.3-0.4 s (Zimmer 2011).

B. DOLPHIN

The group of delphinids found in the Southern California Bight include short-beaked common (*Delphinus delphis*), long-beaked (*D. capensis*), bottlenose (*Tursiops truncates*) dolphins Pacific white-sided (*Lagenorhynchus obliquidens*), Risso's (*Grampus griseu*) dolphins and others.

Dolphins produce echolocation clicks, buzzes, whistles or combinations of two or more. Their echolocation clicks are broadband impulses with a frequency range between 20 and 60 kHz (Hildebrand et al. 2011). They typical have no identifiable ICI. Buzzing is comprised of rapidly repeated clicks. Dolphin whistles are tonal calls that are found mainly between 5 and 20 kHz.

Only Pacific white-sided dolphins and Risso's dolphins produce clicks that contain spectral properties that allow identification down to the species level (Soldevilla et al. 2008).

1. Risso's Dolphin (*Grampus griseus*)

The Risso's dolphins are widely distributed, inhabiting primarily near shore, deep waters of the continental slope and outer shelf (DON 2008). There is a minimum population estimate of 10,000 individuals in the southern California area (Carretta et al. 2007).

Risso's dolphins have been found to dive down to 600 m (DON 2008) and remain submerged up to 30 minutes while foraging. They appear to feed mainly at night (Jefferson et al. 2007).

They are very social animals that are normally found in groups of 30 to several hundred. Calving seasons differ with populations. The Southern California population has its calving season in the fall/winter time period.

2. Pacific White-Sided Dolphin (*Lagenorhynchus obliquidens*)

There are two recognized groups of the Pacific white-sided dolphins (PWSD), the southern and northern groups although these two groups are not visually distinguishable in the field (DON 2008). It is estimated that a population of over 20,000 of both groups exist off the western coast of the continental United States (Carretta et al. 2007). These animals tend to inhabit temperate waters over the outer continental shelf and slope (DON 2008).

PWSD do not appear to be a deep-diving species. Based on feeding habits, it is estimated that their dives are at least 120 m deep and the majority of foraging dives last less than 15 to 25 s (DON 2008).

They can be found in groups ranging from tens to thousands, often mixing with other species such as Risso's dolphins and northern right whale dolphins (DON 2008). Calving season occurs during the summer months (Jefferson et al. 2007).

C. SPERM WHALE (*PHYSETER MACROCEPHALUS*)

The sperm whale is the largest toothed whales species (Jefferson et al. 2007). There is a minimum population estimate of 1,700 sperm whales along the west coast of the continental United States (DON 2008). Sperm whales tend to inhabit the continental slope and waters deeper than 1000 m (Jefferson et al. 2007).

Sperm whales are extremely deep and long divers and have been recorded reaching depths of 3 km or more and for well over an hour. However, it is more common for their foraging dives to be about 400 m deep and last 30–45 min (Jefferson et al. 2007).

Most often they are found in medium to large groups of 20-30 whales, with one bull per breeding group. The females are much more social than the males, traveling in nursery groups (Whitehead 2003). Most births occur in the summer and fall (Jefferson el al. 2007). Sperm whales are seasonal migrants through the Southern California Bight (Dohl 1980).

Sperm whales produce clicks, codas and buzzes. Clicks contain energy from 2 to 20 kHz, with the dominant frequency being around 9 kHz. They typically have an ICI of 0.5–2 s (Zimmer 2011). Codas are sequences of clicks but less intense and lower peak frequencies than regular clicks. Buzzing is comprised of closely spaced clicks (Hildebrand et al. 2011). Sperm whale clicks are too short to support any frequency variations. Their clicks are composed of short pulses separated by 3.7 ms. A single pulse of a sperm whale contains about four oscillations and last about 1 ms (Zimmer 2011).

For this research, we acquired overlapping time periods (June and November 2008) of data from two different recording systems located in close proximity to one another in the San Nicholas basin. The characteristics of each recording system are discussed in the data description section.

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III. DATA DESCRIPTION

We used two sets of passive acoustic recordings collected simultaneously and in close proximity to one another in the San Nicholas Basin via two different recording systems: a bottom-moored HARP and the NPS recording system at SCORE that receives data through near-bottom mounted hydrophones. We will refer to these datasets as "HARP data" and "SCORE data." The goal was to examine the feasibility of applying the protocols commonly used for HARP data analysis to SCORE data. We chose to use the files from data catalogs available to us at the start of this research project that contained the longest continuously-overlapped periods: June 11–13, 2008 and November 23–27, 2008.

The HARP dataset was gathered by SIO from two separate HARP deployments at the same location. The other dataset was collected by NPS through one (in June 2008) and three (in November 2008) hydrophones located within the SCORE network. The characteristics of each system are discussed below.

A. HARP DATA

HARP is a passive acoustic monitoring system that is capable of recording long-term, high-bandwidth acoustic data. Currently, these packages are deployed worldwide in support of long-term behavioral and ecological studies of marine mammals (Wiggins and Hildebrand 2007).

The HARP device is composed of three main components: a data acquisition system, a hydrophone sensor and instrument packaging. The data acquisition system is a low power structure capable of collecting and storing up to 2 TB[1] of information per instrument deployment. It has a sampling frequency of 2 to 200 kHz at 16-bits/sample. The hydrophone sensor is a broadband (10 Hz–100 kHz) device that can be used to record acoustic events from low frequency baleen whales vocalizations to high frequency odontocetes echolocation clicks. The instrument packaging (Figure 1) is so designed that it is compact and easy to deploy and recover (Scripps Whale Acoustic Lab 2007).

[1] Hereafter, HARP specifications are given as of 2008 when the data used here were collected.

The HARP devices used in this research are owned and operated by SIO in La Jolla, CA. The data files used were from two separate deployments, both located near the same site in San Nicolas Basin. The first HARP was deployed from June 4 to August 3, 2008 and located at a depth of 1,012 m. The second one was deployed from October 20 to December 16, 2008 and located at a depth of 1,015 m.

HARP data were continuously recorded for the duration of each deployment at a sampling frequency of 200 kHz. During the data uploading process, the files were copied from a specialized file system to a standard system so that the files could be read by a desktop computer (for more information, see Wiggins and Hildebrand 2007). The files were then converted into XWAV files with a length of approximately five minutes and 114 MB in size. XWAV files are simply WAV files that have a more robust header that include information such as latitude and longitude, depth, start and stop times, etc. The total length of data used in this research from first and second deployments was roughly 52 hours and 81 hours, respectively.

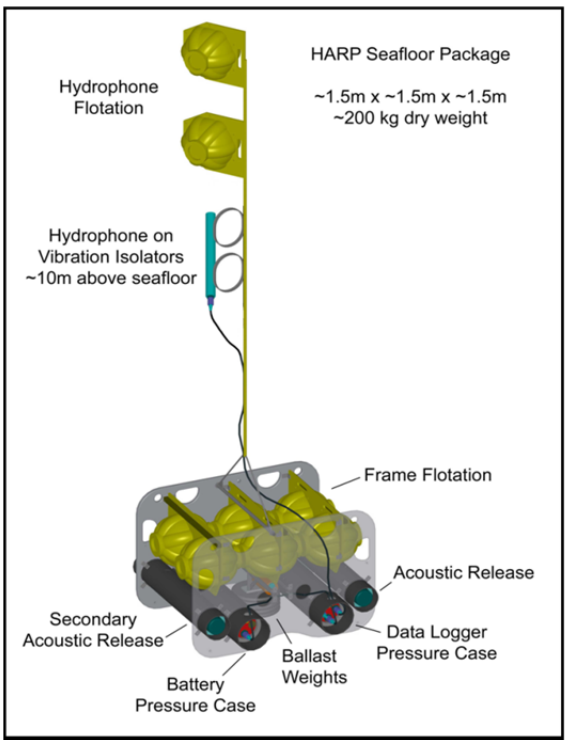


Figure 1. High-frequency Acoustic Recording Package (HARP) seafloor package. The HARP device is composed of three main components: a data acquisition system, a hydrophone sensor and instrument packaging. (From Wiggins and Hildebrand 2007).

B. SCORE DATA

The Southern California Offshore Range complex is located within adjacent waters to San Clemente Island, CA. San Clemente Island has been owned and operated by the United States Navy since 1934. SCORE is state-of-the-art, multi-warfare, integrated training facility that caters to the largest concentration of U.S Navy ships in the world. The bulk of SCORE operations are designed to support training and readiness requirements for Third Fleet, it also facilitates the testing, evaluation, and development of weapon systems and tactics. Within SCORE, lies the instrumented Southern California Anti-Submarine Warfare Range (SOAR) an anti-submarine warfare (ASW) training range. The SOAR hydrophone configuration allows for roughly 670 square miles of underwater tracking area (www.score.com).

SOAR is operated by the Range Operations Center (ROC) personnel at Naval Air Station North Island, CA (www.score.com). The range hydrophones (Figure 2) are permanently mounted and acoustic data are streamed back through undersea cables to San Clemente Island. In cooperation with SCORE Operations, NPS has installed a PAM recording system that receives data through the SCORE hydrophone network. The NPS system can digitize a maximum of 32 channels of hydrophones and is controlled remotely by watch-standers at the ROC. Recording is done on a not-to-interfere with operations basis.

Due to the hydrophone design, the NPS recording system can simultaneously record acoustic events between approximately 8 and 40 kHz and at a sampling frequency of up to 200 kHz. Each channel is patched to a specific hydrophone. One of the 32 channels is always committed to recording a precision timing signal (IRIG-B).

The data used in this research were collected through three range hydrophones hereafter referred to as SCORE A, SCORE B and SCORE C. All three instruments were located within a few kilometers of each other and the SIO HARP (Figure 3). SCORE A, the most northerly, was located at a depth of 1,380 m. SCORE B, which provided data for both June and November, was located at a depth of 1,498 m. SCORE C, the most southerly hydrophone, was located at a depth of 1,148 m.

In June, the only SCORE data in the vicinity to the HARP that were being recorded were through hydrophone SCORE B. The data were continuously recorded at a sampling rate of 96 kHz and written to a hard disk. In November, data from all three hydrophones were available for our use. SCORE A, B and C data were recorded continuously at a sampling rate of 80 kHz. The binary format data were converted to WAV format for visual scanning. The WAV files for June were written in 10 minute long increments each containing 219 MB of data. November's files were converted to WAV files that were 6 minute long and contained 128 MB of data per file. The total hours available for examination for June and November were approximately 59 and 264 hours, respectively.

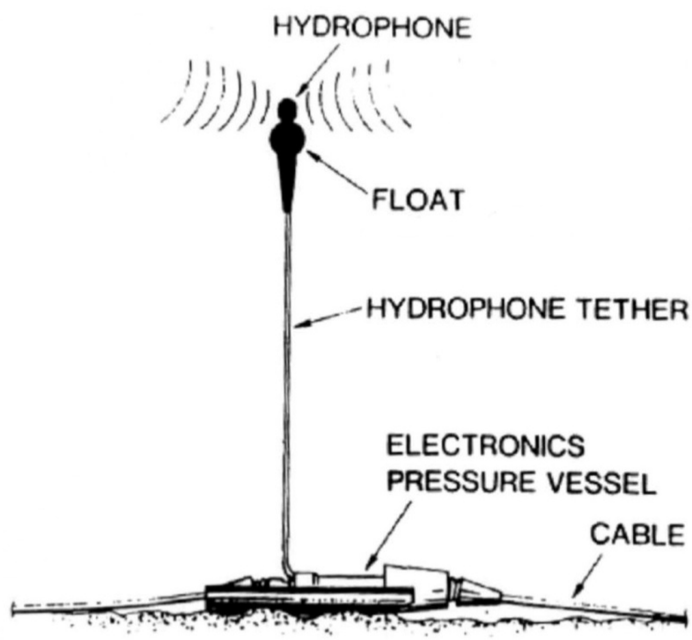


Figure 2. SCORE Range Hydrophone diagram (From Science Applications International Corporation MariProOperations 1991).

C. DATA COMPARISON

An important objective of this research was to find, analyze and identify similar odontocete acoustic events found in both HARP and SCORE datasets that could be used for identifying the presence of different species through the visual scanning process. Because the two recording systems had several primary similarities and differences

which stem from technical specifications of the instruments and the recording parameters applied, it was anticipated that the visual cues analysts rely on to identify key vocalization characteristics of a particular species would be displayed differently in the HARP and SCORE datasets.

1. Similarities

HARP and NPS recording systems are similar in the fact that they both serve as passive acoustic monitors. The HARP was specifically built as a passive acoustic monitoring system. The wide range of species that would likely be encountered was considered in the design parameters of the system. On the other hand, the primary function of SCORE is range tracking in support of naval exercises and the passive acoustic monitoring application is a convenient byproduct. Secondly, both systems record in the frequency band of interest, though the useful bandwidth for HARP is much broader than SCORE. For the purpose of passive acoustic monitoring, high frequency is defined as frequencies at or above 10 kHz. It is in this frequency band that we expect to find odontocete vocalizations.

HARP and SCORE A, B and C hydrophones were located within close proximity to one another. Over the period covered in this research, it was anticipated that vocalizations from the same types of odontocetes would be captured by each system. HARP is located off range to the west of SOAR. The HARP was 7, 8, and 9 km from SCORE A, B, and C hydrophones, respectively (Figure 3).

Another similarity between these systems is the fact that we were able to find two sets of overlapping data: 11 to 13 June 2008 and 23 to 27 November 2008 (Table 1).

Lastly, in this experiment the data were converted into XWAV/WAV files so that they could be analyzed using a near-identical processing method. XWAV and WAV files are similar file formats, but the XWAV files have a more robust heading to include latitude and longitude, depth and start/stop times etc. (Wiggins and Hildebrand 2007).

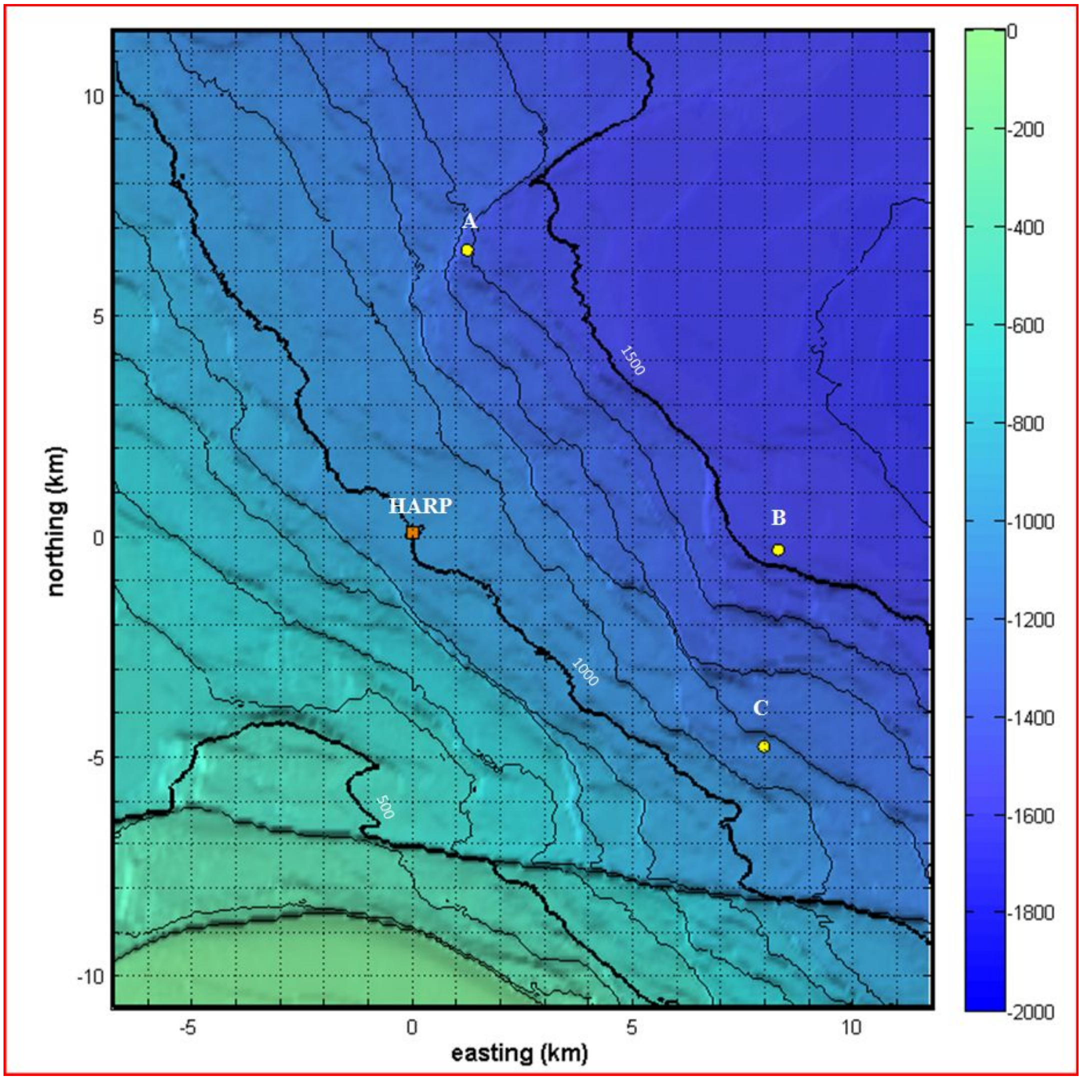


Figure 3. Locations of HARP and SCORE hydrophones A, B and C with bathymetry

Table 1. Dates and total duration of HARP and SCORE data. Total recorded hours of all data available for this research were 456 hours.

	JUNE 2008		November 2008	
	Dates	Hours	Dates	Hours
HARP	13-15	52	23-27	81
SCORE A			23-27	88
SCORE B	13-15	59	23-27	88
SCORE C			23-27	88
Total Hours		**111**		**345**

2. Differences

The main source of the differences between the HARP and SCORE systems are what they were designed to do. As noted earlier, HARP was specifically designed for the passive acoustic recording of marine mammal vocalizations. The capabilities of the HARP hydrophone are due to the advancements in a low-power, high-data-capacity computer technology. This package was made to record high frequency mammal vocalizations on a continuous long-term basis in remote location and independent of the presence of daylight or weather conditions. The HARP is capable of recording data at a sampling rate of up to 200 kHz. The 1.92 TB data storage capacity allows the hydrophone to be deployed for approximately 55 days, when recording continuously at 200 kHz (Wiggins and Hildebrand 2007).

In comparison, the primary purpose of the SCORE hydrophone network is for range tracking during ASW exercises. The ability to record odontocete vocalizations on this system is a very beneficial byproduct; however design considerations built in for operational use are anticipated to affect the system performance as a marine mammal passive acoustic recording system.

A second difference of these systems is the bandwidth window in which they are able to record data. HARP records in the 10 Hz to 100 kHz band, whereas SCORE hydrophones, by design, have more limited bandwidth of approximately 8–40 kHz. This bandwidth limitation is due to the broadband filter, that suppresses frequencies below 10 kHz and above 40 kHz, that each SCORE hydrophone is outfitted with.

Another important difference between the two systems was the sampling frequency at which the data were recorded. As mentioned previously, HARP data were recorded at 200 kHz sampling frequency and SCORE at 96 kHz (June data) and 80 kHz (November data). This gives Nyquist frequencies at 100 kHz for HARP, 48 kHz (June data) and 40 kHz (November data) for SCORE.

Lastly, SCORE hydrophones are outfitted with an automatic gain control (AGC) feature. Each hydrophone has an individual AGC adjustment which lowers the hydrophone response automatically in the presence of strong signals giving them a broader dynamic range. HARP does not have a similar AGC feature. We do not have any calibration information on SCORE instruments, unlike HARP which is calibrated prior to each deployment.

IV. METHODOLOGY

An approach applied earlier to other HARP (see Oleson et al. 2007) will be used to examine HARP and SCORE datasets independently following the below steps.

1. Create long-term spectral averages (LTSAs) for each dataset for 50 Hz frequency bins and 5 s steps for time averaging.
2. Scan the LTSA to detect marine mammal vocalizations and other sound sources.
3. Log each detected acoustic event, i.e., document its start and end time, characteristic frequencies, type of call (whistle, click, buzzing etc.).
4. When possible, classify each acoustic event according to its source, and identify the vocalizing animal to species.

A. TRITON

Triton is Mathwork's Matlab based software that was designed to evaluate acoustics data recorded by Acoustic Recording Packages (ARPs) and HARPs. The data sets are typically long duration, single channel, continuous or scheduled duty–cycles. Triton allows users to quickly review these large data sets via a graphical user interface (GUI). The data sets are transformed into the spectral domain for evaluation as LTSAs (Triton User Guide 2007).

Triton takes WAV or XWAV files and generates the LTSA files by averaging spectra over a period of time and arranging these spectra as frequency-time spectrogram plots. This allows a quick and easy link back to the finer-scale data of the WAV or XWAV files by clicking on the event of interest in the LTSA plot. It also has a log feature that allows the users to make a record of an acoustic event and create JPEGs, WAV and XWAV files (Triton User Guide 2007).

B. LONG-TERM SPECTRAL AVERAGES

In order to analyze this data in a practical and timely manner, the Triton program was used to compress the XWAV and WAV files into LTSAs (Figure 4). LTSAs offer a way to plot large amounts of data in a compressed format while providing a quick link to acoustic events in the original XWAV/WAV data. This mitigates the labor intensive and frankly the unrealistic task of searching through short duration spectrograms for individual calls.

The LTSA is a three-dimensional time-frequency energy plot where each frequency spectrum plotted along time is averaged over a longer period than one windowed frame of a Fast-Fourier Transform (FFT). The averaged spectra are then plotted sequentially and color coded (Triton User Guide 2007).

In order to create the LTSAs, long-term spectrogram parameters must be set based on the data sampling rate and target vocalizations. In this research, five seconds was the length of time chosen to average each time bin and 50 Hz was the frequency bin size. We chose to make individual LTSAs for each separate day for easy of scanning and to lessen computation effort it took to create the LTSAs.

Once the LTSAs were created they were displayed in the plot window of Triton (Figure 4). On the bottom right corner of this window, the LTSA plot details are listed. Here the sampling rate (Fs), the time average used to create the LTSA (Tave), FFT size (NFFT), brightness (B) and contrast (C) used to generate the plot are found.

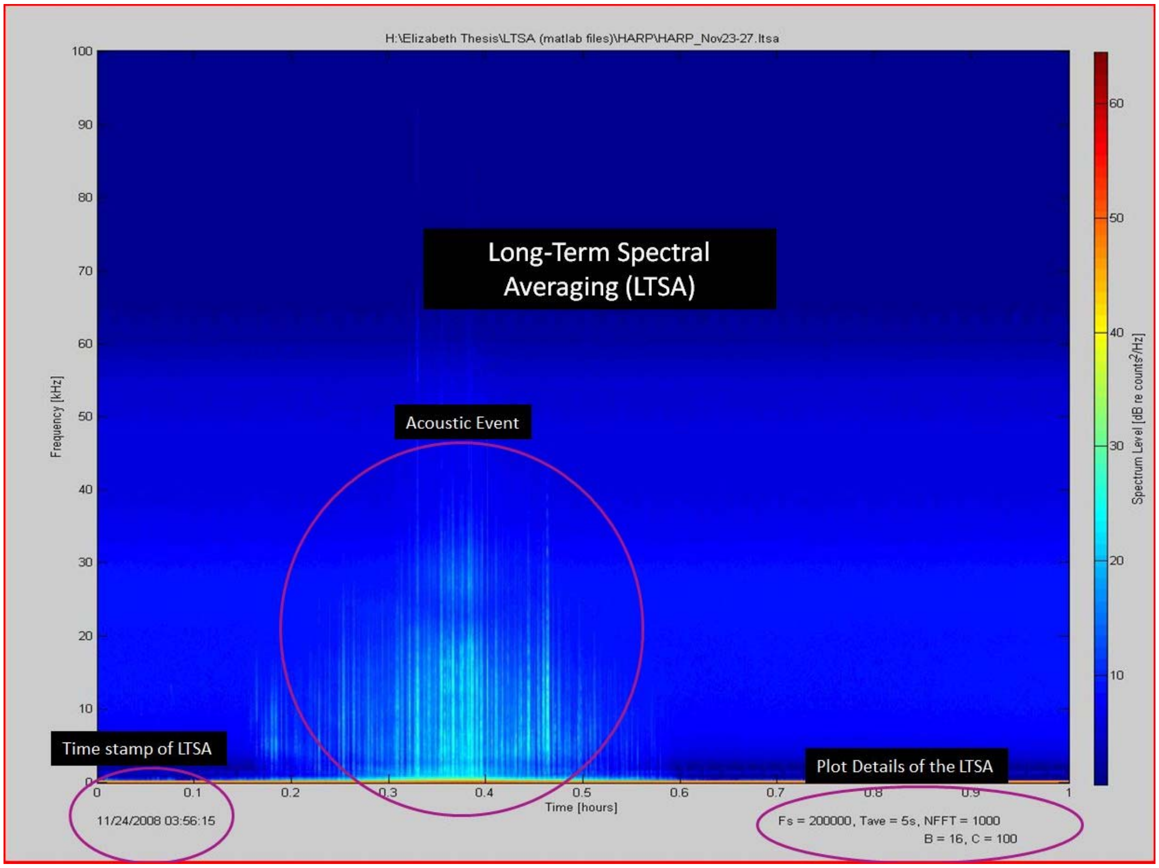


Figure 4. Triton's plot window. Allows users to search for any acoustically significant events. The botton left corner lists the day and time of the file being viewed. The bottom right coner list the plot details of the LTSA.

The control window (Figure 5) contains the controls used to select plot and time step lengths, to adjust the brightness and contrast, and the buttons used to navigate through the LTSA and individual XWAV files.

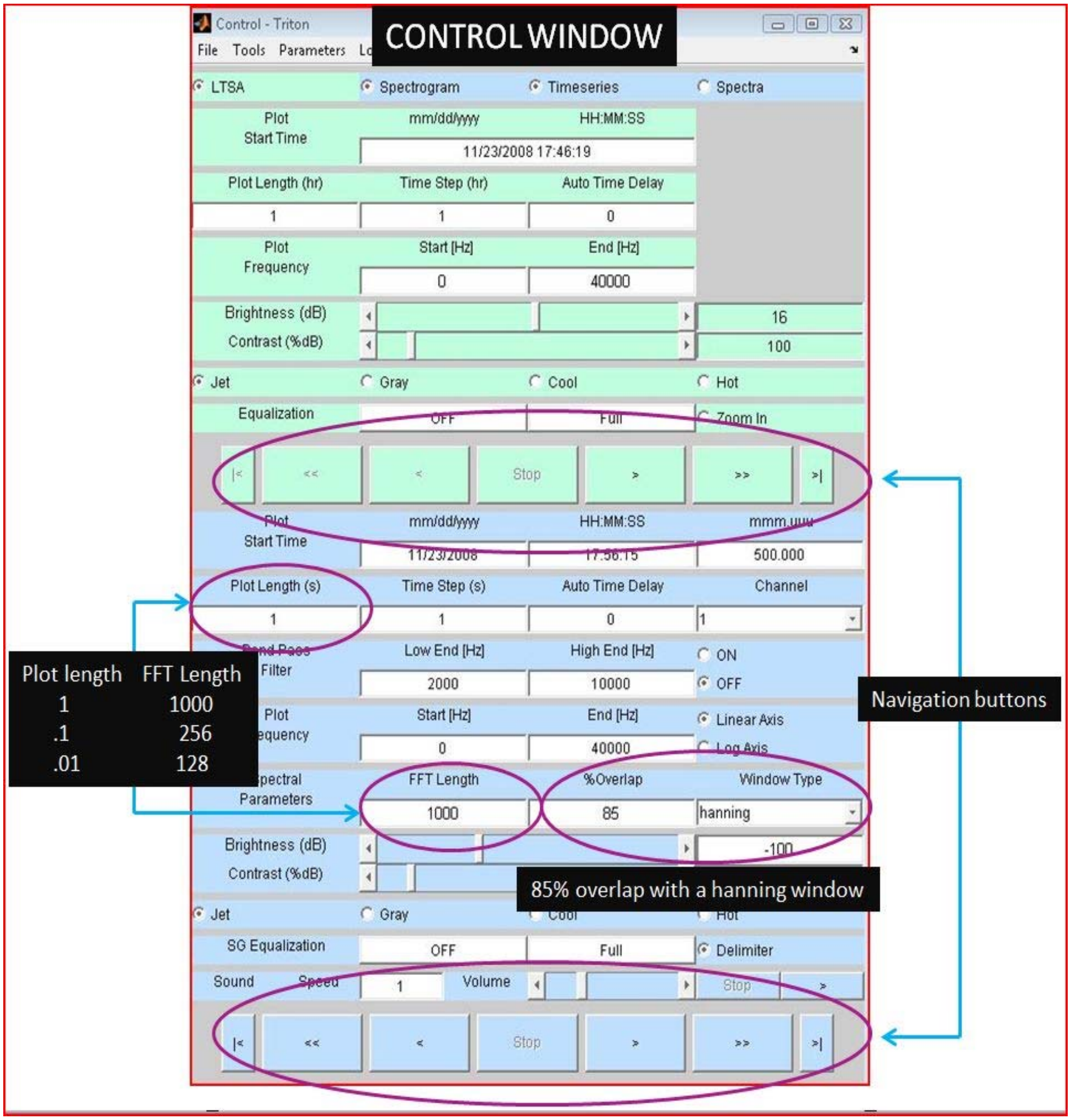


Figure 5. Triton control window. Allows users to adjust LTSA plot settings, brightness, contrast, plot length, FFT length, overlap and navigation. FFT parameters used for different plot length are shown in the corresponding black box.

C. SCANNING

Once an acoustic event of interest was identified in the LTSA, the Triton user could click anywhere in that event and generated the spectrogram from the original XWAV/WAV files that correspond to that particular time chosen (Figure 6).

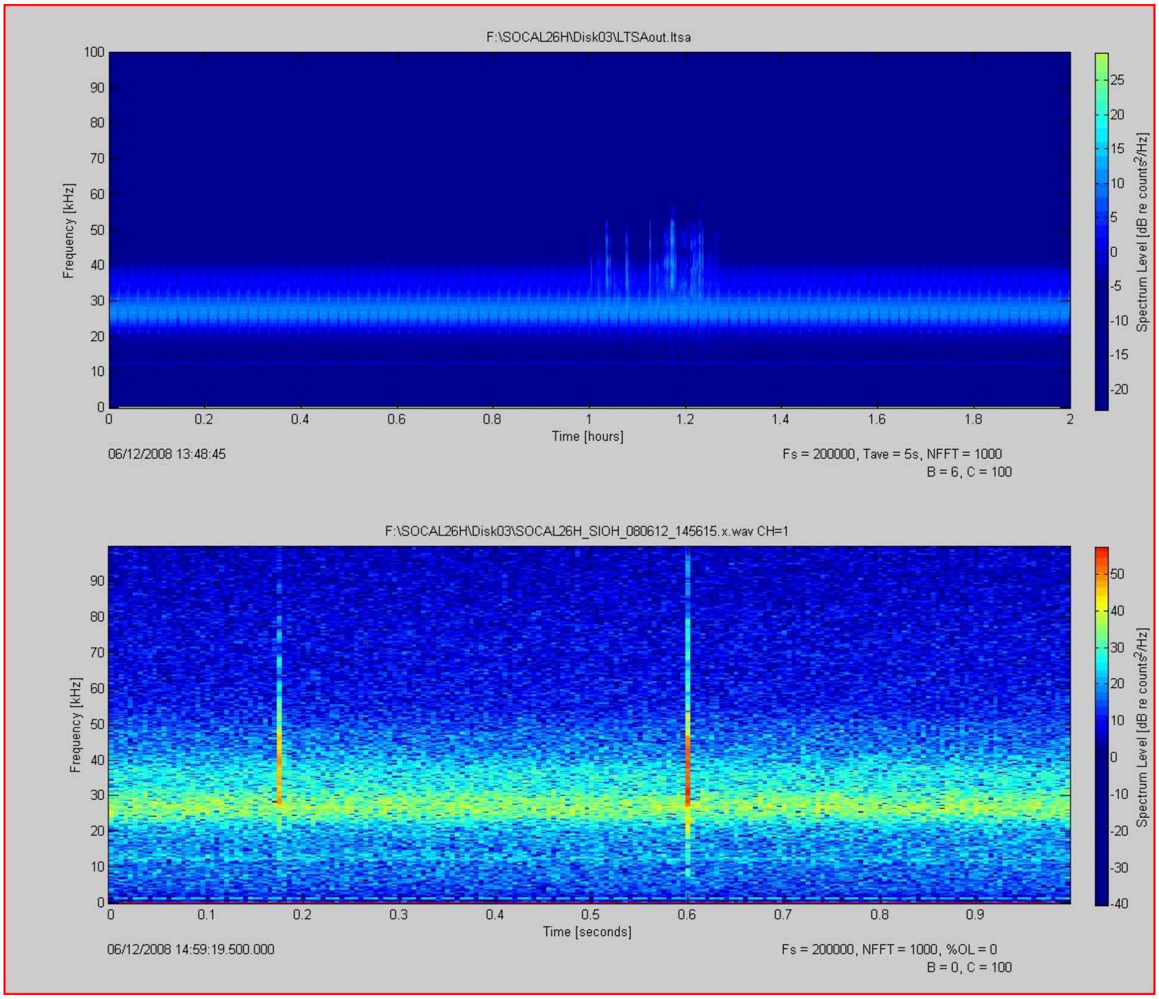


Figure 6. An example of beaked whale detection. An acoustic event of interest was found in the LTSAs (top panel) and once it was clicked on a zoomed in spectrogram (bottom panel) of that event was generated. Notice that the time scale of the LTSA plot is two hours and the spectrogram is one second length panel.

Once the spectrogram was opened, the control window was updated with the spectrograms control window. In this research, the FFT settings used were an 85% overlap, a Hanning window and FFT length of 1000 points. By having the spectrogram window length at one second, inter-click intervals and peak frequency could be determined. From here individual clicks were enlarged to determine click length, shape or if an upsweep was present. This was accomplished by making the window size and FFT lengths shorter, for example, if window length was 0.1 seconds, we made the FFT length 256 or if the window length was 0.01 s we made the FFT length 128.

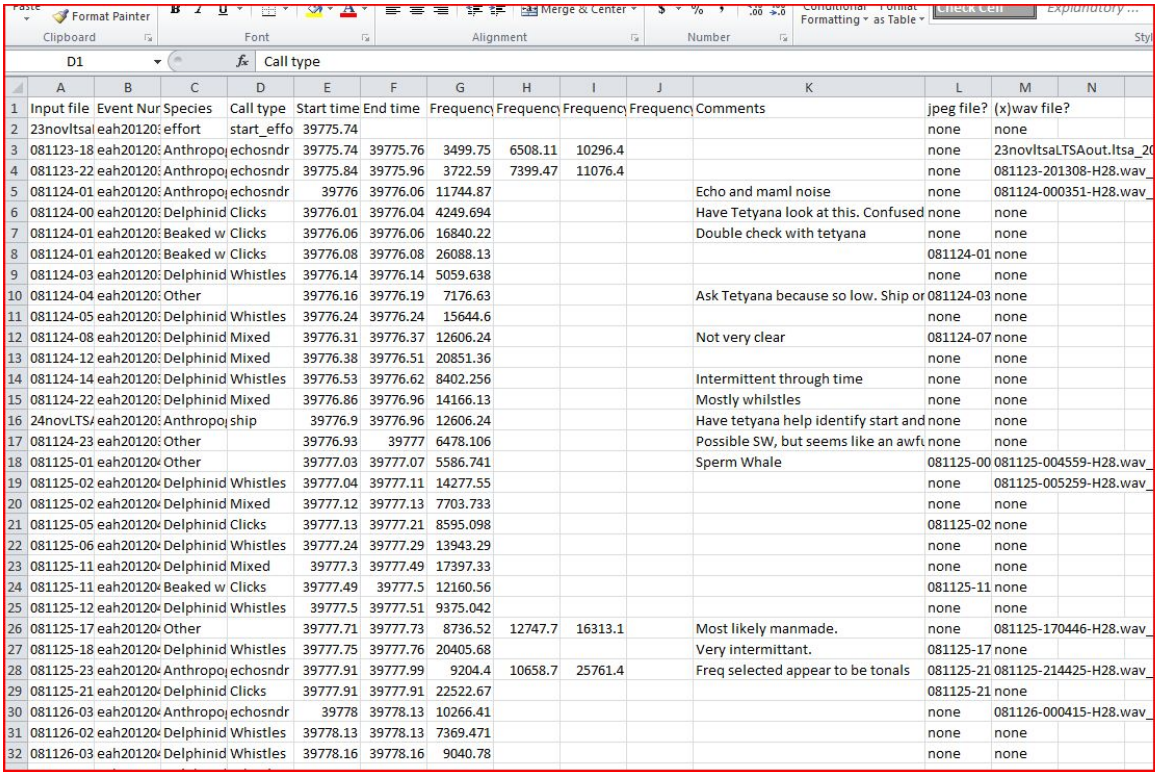
Lastly, a time series window and control window were opened by clicking on the Timeseries radio button at the top of the control window (Figure 5). The time series window provides a direct plot of the sound pressure measurements. This presentation is a very useful way to describe signals that express large amplitude variations, such as all cetacean clicks (Zimmer 2011).

Every HARP and SCORE dataset was scanned independently to ensure marine mammal detections in each were independently determined without influence form the other data sets.

D. LOGGING

As we scanned through the data, all acoustic events of interest were logged in an Excel sheet using Triton's logger feature. The information on these events of interest was divided up into categories to include: detections species, call types, start and end times, frequencies of interest, and comments, and was filed (Figure 7). This function allowed us to create a record of acoustic events and provided a roadmap to where the JPEGs and XWAV files were stored. We were also able to sort our log files by species, call type, start/end times, etc. This allowed us to create simple statistics of the breakdown of detections by species.

The Excel files were very easy to use with Matlab software. We were able to create Matlab codes that retrieved the data from the log files and used the data to create occurrence diagrams, averaged clicks figures and compute statistical analysis on our information.



	Input file	Event Nur	Species	Call type	Start time	End time	Frequency	Frequency	Frequency	Frequency	Comments	jpeg file?	(x)wav file?
2	23novltsal	eah20120	effort	start_effo	39775.74							none	none
3	081123-18	eah20120	Anthropo	echosndr	39775.74	39775.76	3499.75	6508.11	10296.4			none	23novltsaLTSAout.ltsa_20
4	081123-22	eah20120	Anthropo	echosndr	39775.84	39775.96	3722.59	7399.47	11076.4			none	081123-201308-H28.wav_
5	081124-01	eah20120	Anthropo	echosndr	39776	39776.06	11744.87				Echo and maml noise	none	081124-000351-H28.wav_
6	081124-00	eah20120	Delphinid	Clicks	39776.01	39776.04	4249.694				Have Tetyana look at this. Confused	none	none
7	081124-01	eah20120	Beaked w	Clicks	39776.06	39776.06	16840.22				Double check with tetyana	none	none
8	081124-01	eah20120	Beaked w	Clicks	39776.08	39776.08	26088.13					081124-01	none
9	081124-03	eah20120	Delphinid	Whistles	39776.14	39776.14	5059.638					none	none
10	081124-04	eah20120	Other		39776.16	39776.19	7176.63				Ask Tetyana because so low. Ship or	081124-03	none
11	081124-05	eah20120	Delphinid	Whistles	39776.24	39776.24	15644.6					none	none
12	081124-08	eah20120	Delphinid	Mixed	39776.31	39776.37	12606.24				Not very clear	081124-07	none
13	081124-12	eah20120	Delphinid	Mixed	39776.38	39776.51	20851.36					none	none
14	081124-14	eah20120	Delphinid	Whistles	39776.53	39776.62	8402.256				Intermittent through time	none	none
15	081124-22	eah20120	Delphinid	Mixed	39776.86	39776.96	14166.13				Mostly whilstles	none	none
16	24novLTS/	eah20120	Anthropo	ship	39776.9	39776.96	12606.24				Have tetyana help identify start and	none	none
17	081124-23	eah20120	Other		39776.93	39777	6478.106				Possible SW, but seems like an awfu	none	none
18	081125-01	eah20120	Other		39777.03	39777.07	5586.741				Sperm Whale	081125-00	081125-004559-H28.wav_
19	081125-02	eah20120	Delphinid	Whistles	39777.04	39777.11	14277.55					none	081125-005259-H28.wav_
20	081125-02	eah20120	Delphinid	Mixed	39777.12	39777.13	7703.733					none	none
21	081125-05	eah20120	Delphinid	Clicks	39777.13	39777.21	8595.098					081125-02	none
22	081125-06	eah20120	Delphinid	Whistles	39777.24	39777.29	13943.29					none	none
23	081125-11	eah20120	Delphinid	Mixed	39777.3	39777.49	17397.33					none	none
24	081125-11	eah20120	Beaked w	Clicks	39777.49	39777.5	12160.56					081125-11	none
25	081125-12	eah20120	Delphinid	Whistles	39777.5	39777.51	9375.042					none	none
26	081125-17	eah20120	Other		39777.71	39777.73	8736.52	12747.7	16313.1		Most likely manmade.	none	081125-170446-H28.wav_
27	081125-18	eah20120	Delphinid	Whistles	39777.75	39777.76	20405.68				Very intermittant.	081125-17	none
28	081125-23	eah20120	Anthropo	echosndr	39777.91	39777.99	9204.4	10658.7	25761.4		Freq selected appear to be tonals	081125-21	081125-214425-H28.wav_
29	081125-21	eah20120	Delphinid	Clicks	39777.91	39777.91	22522.67					081125-21	none
30	081126-03	eah20120	Anthropo	echosndr	39778	39778.13	10266.41					none	081126-000415-H28.wav_
31	081126-02	eah20120	Delphinid	Whistles	39778.13	39778.13	7369.471					none	none
32	081126-03	eah20120	Delphinid	Whistles	39778.16	39778.16	9040.78					none	none

Figure 7. Excel log file. The log file is a diary of the scanning process. This allows the user to quickly revisit any acoustic event of interest.

E. SPECIES-LEVEL IDENTIFICATION OF ACOUSTIC EVENTS

Identification of detected sounds was based on previously established distinctive features of specific species vocalizations in HARP data. Beaked whales, dolphins and sperm whales were the three marine mammals we identified in our scanning. When scanning SCORE data, we used the HARP based characteristics as a starting point, but found several differences in feature presentation that are discussed below.

1. Cuvier's Beaked Whale

a. Description of Characteristics

Beaked whales produce echolocation clicks that are very distinct from those of any other species. Their clicks last about 200 µs and span over a frequency range of 20 to 60+ kHz, with the dominant frequency at 40 kHz. Beaked whale clicks have a very distinct upsweep in frequency. This upsweep occurs over a 0.15 ms interval. Their clicks also have a very specific inter-click interval (ICI) of 0.3–0.4 s (Zimmer 2011).

In the HARP and SCORE LTSAs, beaked whale acoustic events take on an icicle shape. They tend to show the higher energy concentrations in a more intermittent pattern than that of dolphins (Figure 8A). It was imperative that these events be viewed in the higher resolution screen of the spectrogram. It was in the spectrogram that we were able to identify the characteristic frequency upsweep and ICI (Figure 8B and C).

In cases where the clicks were distorted in the spectrogram, we then used click time-series to distinguish beaked whale clicks from dolphin clicks. The waveform (Figure 8D) of a beaked whale click is more robust than the waveform of a dolphin click. Their clicks are made up of amplitude-modulated oscillations, usually lasting about 200 µs (Zimmer 2011) and contained a notch in the waveform (Figure 9).

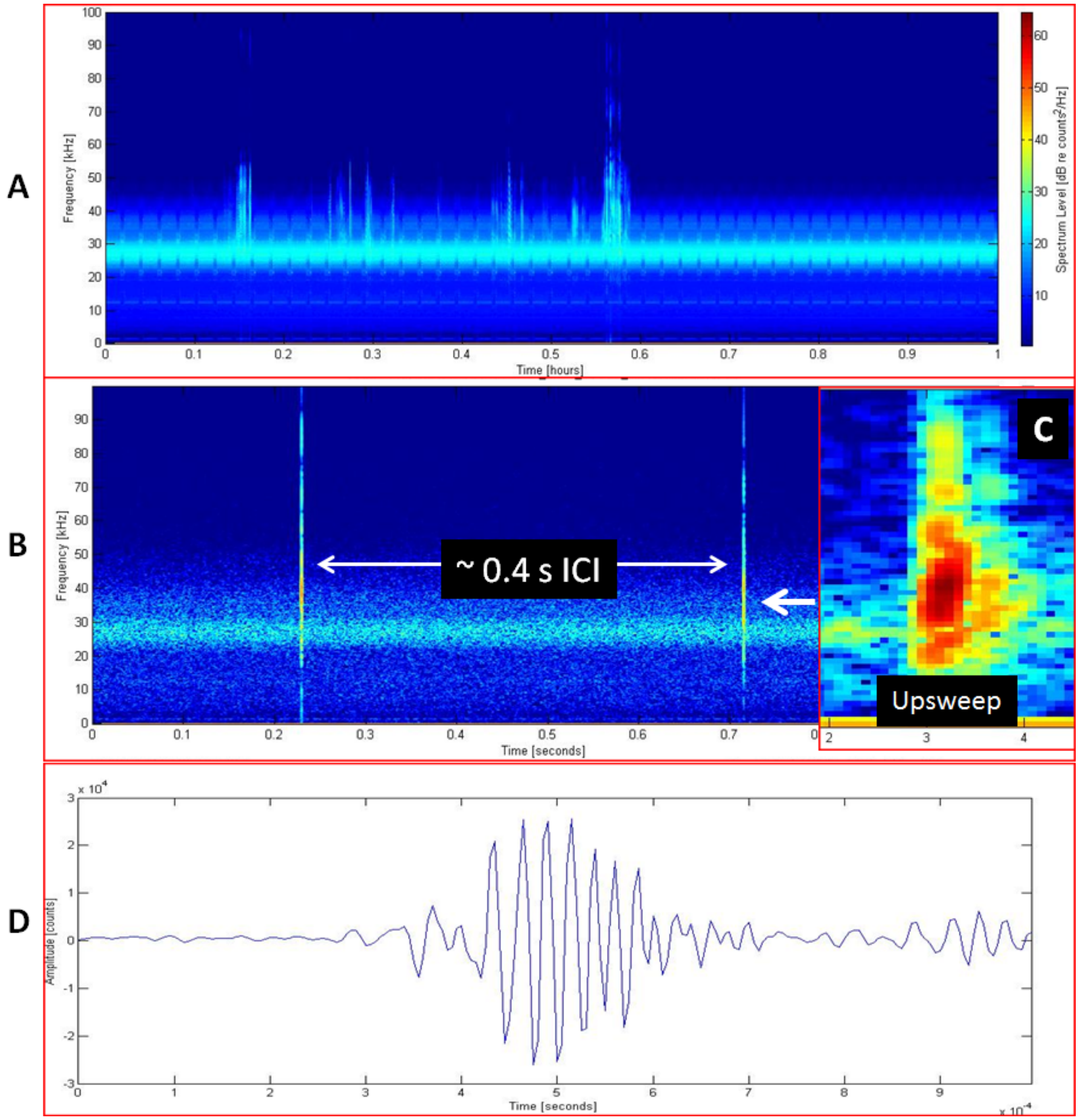


Figure 8. Beaked whale clicks detected in HARP data:
(A) representation of the event in 1-hour long LTSA;
(B) spectrogram of a 1-sec data with two echolocation clicks;
(C) spectrogram of a 250 µs long echolocation click;
(D) 1 ms timeseries plot of a single click.

b. Differences in Characteristics

In both HARP and SCORE LTSAs the acoustic events of beaked whales looked similar except for the fact that the higher-frequency parts of the events were cut-off in the SCORE LTSAs due to filtering and sampling frequency (Figure 9A).

The ICI of beaked whale clicks in the SCORE data were still approximately 0.4 s (Figure 9B). However, the presentation of the upsweep in the spectrogram was distorted and even at times unrecognizable. Due to this quality we had to rely more heavily on the waveform characteristics to identify the marine mammal species than when scanning HARP data.

In SCORE, the waveform for beaked whales was still more robust than dolphin clicks. The notch however was not always as detectable in SCORE as it was in HARP. We also observed several instances where it seemed as if two clicks were received at almost the same time, causing the waveform to double in length (Figure 9). We hypothesize that this is due to multiarrivals of off-axis clicks. Identifying beaked whales was much easier in HARP data than in SCORE; as we usually had to look at several more clicks in the SCORE data in order to identify the click as being produced by a beaked whale.

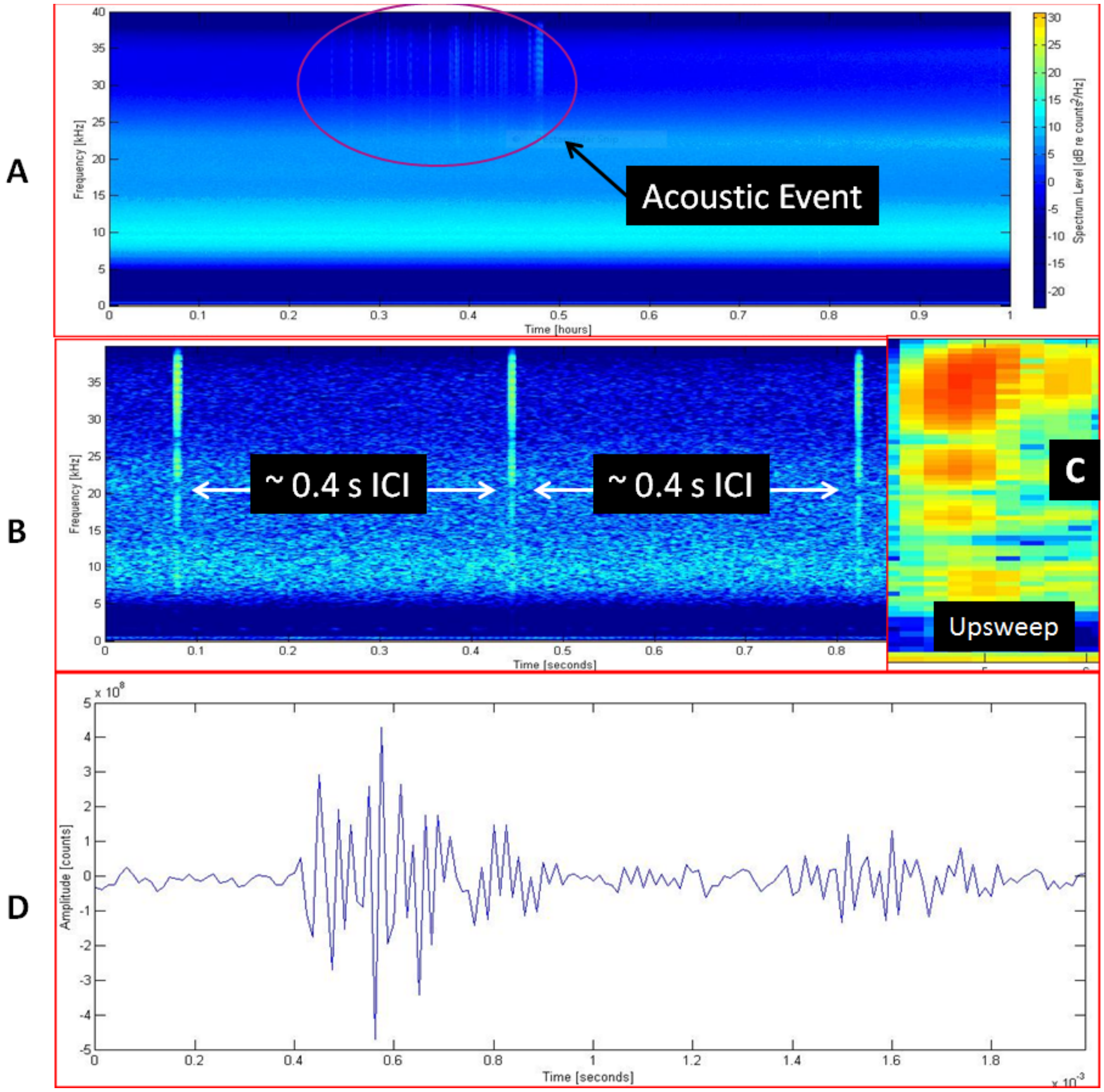


Figure 9. Beaked whale clicks in SCORE B dataset: (A) representation of the event in 1-hour long LTSA; (B) spectrogram of a 1-sec data with three echolocation clicks; (C) spectrogram of a 200 μs long echolocation click; (D) 2 ms timeseries plot of a single click.

2. Dolphins

a. Description of Characteristics

Dolphins produce echolocation clicks, buzzes, whistles or a combination of two or more. Their echolocation clicks are broadband impulses with a frequency range between 20 and 60 kHz (Hildebrand et al. 2011). They typical have no identifiable ICI. Buzzing is comprised of rapidly repeated clicks and was sometimes apparent in the

LTSA. Dolphin whistles are tonal calls that are found mainly between 5 and 20 kHz. They vary in frequency modulation and duration (Hildebrand et al. 2011) and were very visible in the LTSAs (Figures 10 and 11).

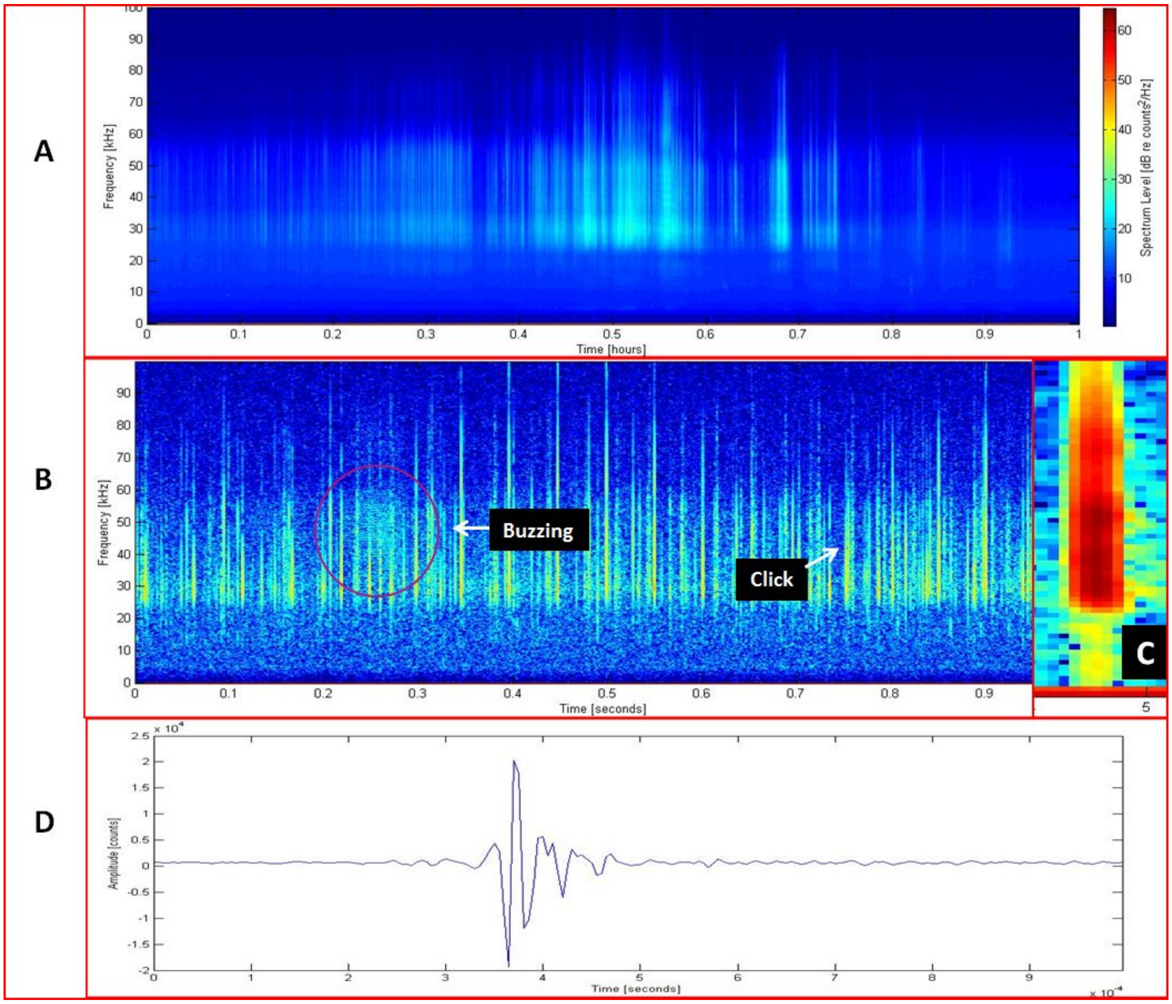


Figure 10. Unidentified dolphin vocalizations in HARP: (A) representation of the event in 1-hour long LTSA; (B) spectrogram of a 1-sec data with no clear ICI and buzzing; (C) about a 100 μs spectrogram of individual click; (D) 1-ms timeseries plot of a single click

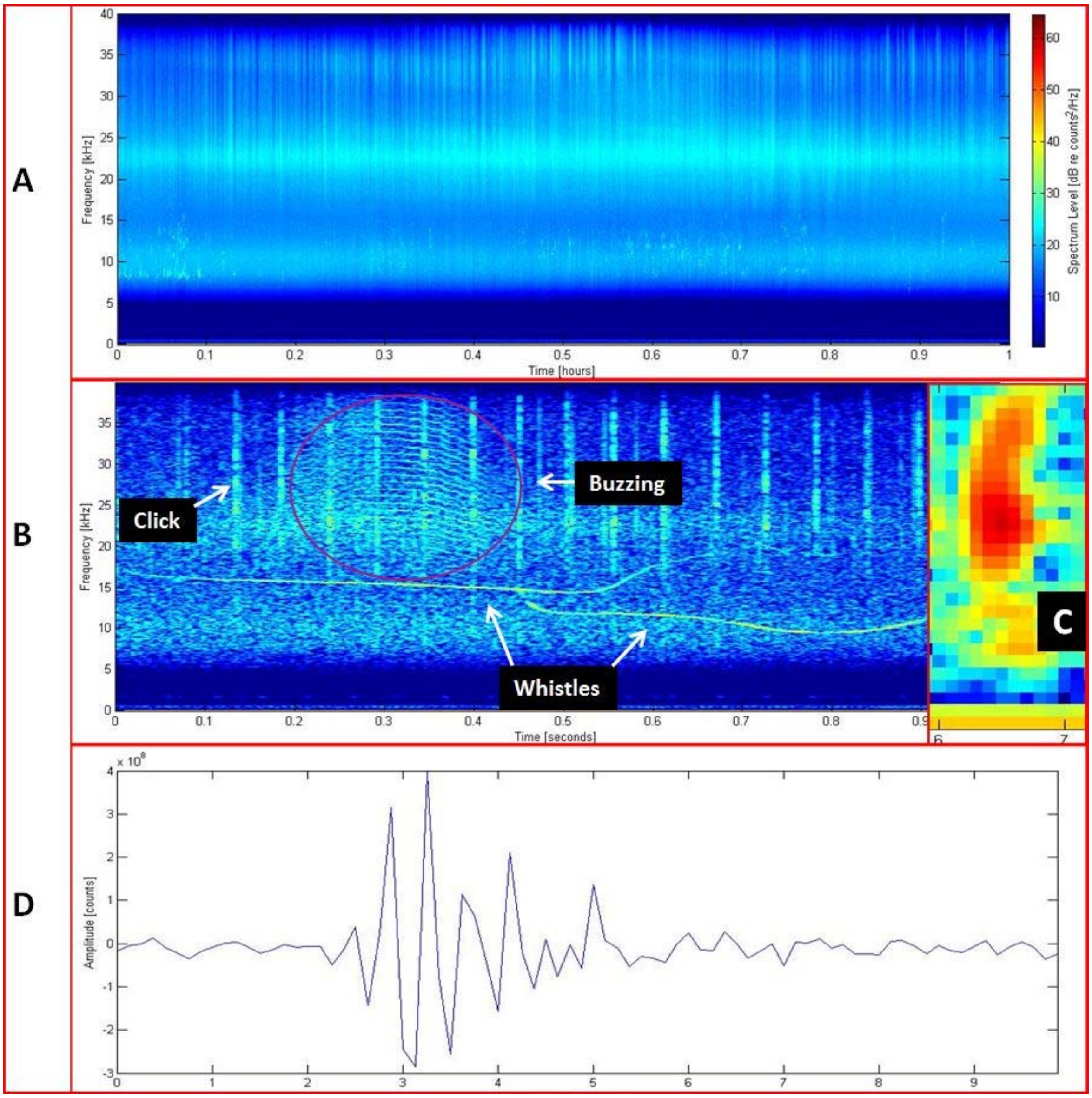


Figure 11. Unidentified dolphin vocalizations in SCORE: (A) representation of the event in 1-hour long LTSA; (B) spectrogram of a 1-sec data with no clear ICI, buzzing and whistles; (C) about a 100 μs spectrogram of individual click; (D) 1-ms timeseries plot of a single click

The waveform of the dolphin click is very short, usually only lasting 30 μs (Zimmer 2011) and made up of less oscillations compared to the beaked whale waveform. We identified dolphin clicks by not having the characteristics of those of the beaked whale clicks. The absence of an upsweep in frequency or any identifiable inter-

click interval would allow us to categorize the vocalization as belonging to a dolphin. On several occasions dolphin clicks were accompanied by whistles and/or buzzing, which provided a good idea that they were dolphins from first glance at the LTSA (Figure 11). This was then continued by checking the ICI and click duration of the event.

Pacific white-sided dolphins can be identified to species by the distinctive banding patterns in the LTSA. Their echolocation clicks have energy peaks at 22.2, 26.6, 33.7 and 37.3 kHz (Soldevilla et al. 2008).

Risso's dolphins can also be identified to species by the distinctive banding patterns in the LTSAs. Their echolocation clicks have energy peaks at 22.4, 25.5, 30.5, and 38.8 kHz (Soldevilla et al. 2008).

b. Differences in Characteristics

In the LTSAs the acoustic events of dolphins were very similar in both data sets. How bright the vocalizations appeared in the HARP and SCORE LTSAs were equal to one another, Figures 10 and 11, respectively. The only difference was the SCORE device's auto gain feature sometimes would cut out some of the energy when the dolphins' received signal was really strong, which could mean that they were close to the instrument or that there were numerous animals present. HARP devices do not have this function.

The lack of a clear ICI in both HARP and SCORE spectrogram was a clear indicator that dolphins were present. The presence of buzzing and whistles was always the clearest indicator in both data sets (Figure 11).

In both HARP and SCORE, the waveform of the dolphin echolocation click appeared shorter and simpler than that of the beaked whale click. We found the identification process of dolphins in HARP and SCORE to be similar.

3. Sperm Whale

a. Description of Characteristics

Sperm whales produce clicks, codas and buzzes. Clicks contain energy from 2 to 20 kHz, with the dominant frequency of approximately 9 kHz. They typically have an ICI of 0.5-2 s (Zimmer 2011). Codas are sequences of clicks but less intense and of lower peak frequencies than regular clicks. Buzzing is comprised of closely spaced clicks (Hildebrand et al. 2011). Sperm whale clicks are too short to support any frequency variations. Their clicks are composed of short pulses separated by about 3.7 ms. A single pulse of a sperm whale contains about four oscillations and last about 1 ms (Zimmer 2011).

In the LTSAs, we found it quite easy to confuse sperm whales clicks with anthropogenic (ship) acoustic events. Once the spectrogram was produced, we could distinguish the continuous, steady sperm whales clicks from the erratic impulses of mechanical noise and propeller cavitation of a ship. Another way we distinguished sperm whale clicks from ship noise was to listen to the file. Sperm whale pulses sound like a metronome, very methodical, whereas ship noise in these frequencies sounds erratic.

b. Differences in Characteristics

In SCORE LTSAs, the acoustic events of sperm whales were distorted due to the filter roll-off below 10 kHz. This caused the lower-frequency content of the acoustic events to be cut off, which in several instances made the identification between sperm whale and anthropogenic (ship) to be very difficult (Figure 12).

The presentations of the sperm whale clicks in HARP and SCORE spectrograms were comparable. In SCORE data, the lower frequency parts of the clicks were cut off due to filter roll-off. We also have several instances in SCORE data where the clicks would span the entire frequency band (up to 40 kHz). In both data sets, the acoustic event could always be identified as sperm whale by listening to the file. In both HARP and SCORE sperm whale clicks sound like a metronome.

We did not use the waveform as a way of identifying a sperm whale in either HARP or SCORE. However, the waveforms appear similar. We found more sperm whales present on SCORE data than HARP. However, the filter roll-off of SCORE made it more difficult to identify

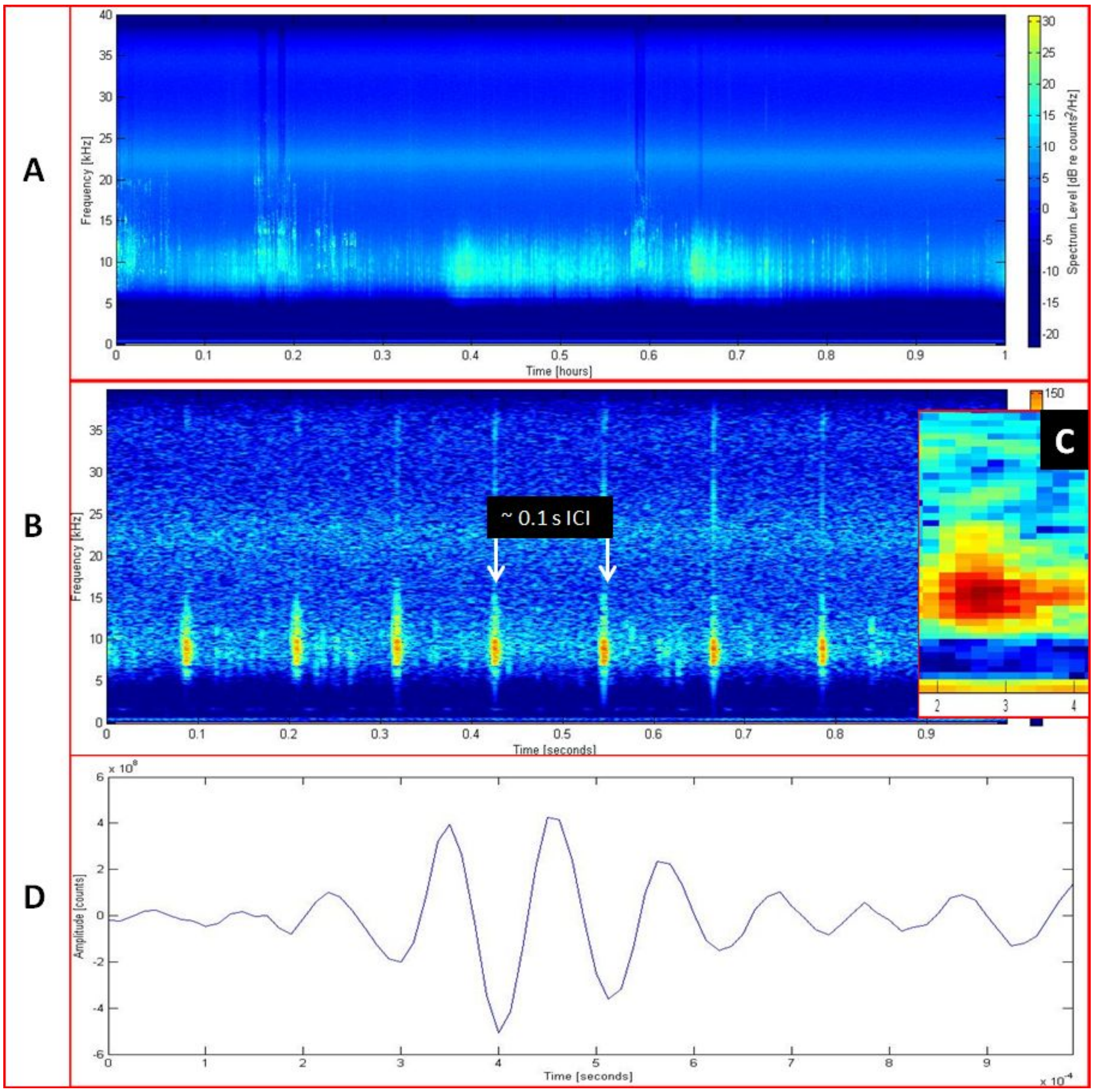


Figure 12. Sperm whale vocalizations in SCORE: (A) 1-hour long LTSA; (B) spectrogram of 1-s long data; (C) about a 200 µs spectrogram of a single click; (D) 1 ms waveform of a single click.

V. RESULTS

We analyzed six datasets of passive acoustic recordings independently for the presence of odontocetes. The total data length was approximately 456 hours, about 30% from HARP recordings and the other 70% from SCORE data. The total duration of detected marine mammal vocalizations in all datasets was about 140 hours with approximately 20% and 80% of the detections made in HARP and SCORE recordings, respectively.

Breakdown of the total detection time between individual datasets by identified species and vocal elements is shown in Table 2.

Table 2. Marine mammal detections in HARP and SCORE datasets. Percentages are given relative to total duration of an individual dataset.

	13–15 JUNE 2008				23–27 NOVEMBER 2008							
	HARP		SCORE (B)		HARP		SCORE (A)		SCORE (B)		SCORE (C)	
	hrs	%	hrs	%	hrs	%	hrs	%	hrs	%	hrs	%
Beaked Whale	1.93	3.7	11	18.6	1	1.2	1.8	2.1	4.6	5.3	4.4	5.2
Dolphin	1.2	2.4	3.4	5.6	15.5	18.6	25	29	25.5	29.7	19.1	22.2
Mixed	1.2	2.4	1.5	2.5	9.3	11.4	14.1	16.4	21	24.3	16.7	19.5
Clicks	0	0	1.4	2.3	5.7	7	4.5	5.2	3.9	4.5	1.8	2.1
Whistle	0	0	0.5	.8	0.1	0.1	6.4	7.4	0.7	0.8	0.6	2.1
Sperm Whale	0	0	0	0	4	4.9	3.1	3.5	7	8.2	9.3	10.9
Dataset duration	52	100	59	100	81	100	88	100	88	100	88	100

It is very important for us to define nomenclature as used in this research:

1. *Source* will refer to a marine mammal species (group of species) or manmade mechanism, to which a vocalization or sound can be attributed. In this research marine mammal sources were categorized as beaked whale, dolphin, or sperm whale.

Anthropogenic sounds were classified as ship or echosounder. When possible, dolphin vocalizations were further classified as Pacific white-sided dolphin or Risso's dolphin. Those not identifiable to species were logged as "unidentified dolphin." Sources that we were unable to classify with high certainty were logged as "unidentified sounds." In this research, a conservative approach was applied to species-level identification of detected sounds. This was done in order to keep the number of false positive identifications low. We acknowledge that this practice has most likely under-estimated the presence of certain species.

2. *Vocal elements* refer to individual distinct sounds or call types to include click, buzzing (or burst pulse), and whistle that comprise a marine mammal vocalization.

3. *Detection*/*acoustic detection* is a presence of a vocalization or anthropogenic sound in a five second time bin. During the scanning process all attempts were made to find the very first and last vocal elements of a detected acoustic event (defined below). Nevertheless, it is likely that event duration was underestimated because vocalizations are usually weakest (and thus harder to detect) in the beginning and end of an acoustic event. To account for the possible underestimation, we grouped detections into five second bins for visualization purposes and statistical estimates.

4. *Event/acoustic event* is defined as a continuous series of detections that presumably comes from the same source. In this research, we define continuous to mean that the maximum separation of neighboring detections do not exceed 30 minutes.

Figures 13–18 show occurrence diagrams categorized by species, time and recording systems. As can be seen in the diagrams below, there were instances where events aligned, especially for those of longer duration. This means that conspecific animals were concurrently detected in different datasets. We are not implying that these vocalizations are produced by the same individual animal or even the same group of animals. However, existence of such "concurrent" detections confirms that these species were present in our area of interest and were successfully detected and identified by us in different datasets.

Below, we analyze species composition of marine mammal detections as well as the distribution of detections in space (between different instruments) and time (for two analyzed time periods). This allows us to investigate two questions: which species were present in our area of interest during the analyzed period and secondly, how coherent the spatio-temporal variability picture for odontocetes is based on the detections we made in HARP and SCORE data. The first question is important because the identification process relies on distinctive features for each species, often with known regional variations, such as two separate types of Pacific white-sided dolphin echolocations clicks.

The second could be used as a measure of the detection quality. For example, sperm whales were concurrently detected on 3 of the 4 hydrophones in the November data set. SCORE C, which located just 4 km from SCORE B, did not have sperm whale detections. This was an unexpected result because sperm whale echolocation clicks can be detected at ranges over 10 km. After further analysis of detection results, this inconsistency was explained. We suspect that sperm whales clicks were registered by SCORE C hydrophone, but were categorized as unidentified sounds due to the conservative approach we used to avoid false positive identification.

A. BEAKED WHALES

Although beaked whales tend to travel in smaller groups than dolphins and their echolocation clicks are very directional, we found numerous vocalizations in both HARP and SCORE data that were identified as those produced by beaked whales. All beaked whale detections were categorized as clicks.

Based on known specific features of echolocation clicks, we concluded that most of the beaked whale vocalizations can be attributed to Cuvier's beaked whale (*Ziphius cavirostris*). As will be discussed below, SCORE recordings of beaked whale clicks contained enough information to make the same conclusion for the SCORE detections.

1. Seasonal Differences

During the June time period, beaked whale vocalizations made up more than half of all marine mammal detections, 61% and 77% for HARP and SCORE B data sets, respectively. The percentages of beaked whale vocalizations for the November time

period were much lower in all datasets. Only 5% of all marine mammal detections in the November HARP dataset were identified as beaked whale clicks. This rate was equal to 6, 12 and 14% for SCORE A, B, and C datasets, respectively.

Since durations of beaked whale detections were comparable for individual June and November datasets (Table 2), the difference in the presence rate of beaked whales between these two time periods can be explained by a higher presence rate of dolphins and sperm whales in November rather than seasonal patterns in beaked whale migration. This is supported by the fact that Cuvier's beaked whales are known to be present throughout the year in the Southern California Bight (Dohl 1980).

2. Spatial Differences

In the June 2008 data, HARP and SCORE B instruments recorded 5 and 23 beaked whale events, respectively. In one instance, beaked whales were detected concurrently in both datasets. In the November 2008 data, HARP, SCORE A, B, and C instruments recorded 3, 8, 9 and 10 beaked whale events, respectively. In five instances beaked whale vocalizations were recorded concurrently in SCORE B and SCORE C datasets, which are separated by the least distance of all instruments in this research. Concurrent detections of conspecific animals were made once in all four datasets. The longest vocalization event lasted 70 minutes and was detected in the SCORE B dataset. We can attribute the above differences in the detection rate to high directionality of beaked whale echolocation clicks, distance between hydrophones, and hydrophone depth. SCORE B hydrophone was located at the deepest depth of approximately 1500 m.

B. DOLPHINS

Dolphins usually travel in large groups and are very social animals, making their vocalizations very loud. They are also very numerous in the area surrounding the San Nicholas Basin. Thus as expected, multiple vocalizations in all datasets were identified as those produced by dolphins. We were able to identify four acoustic events as Pacific white-sided dolphin (*Lagenorhynchus obliquidens*). Two of the events were found in June HARP data, one event in November HARP data and one event in November SCORE C data. Three of these PWSD vocalizations contained clicks only, the other

found in June HARP events contained mixed vocalizations. We did not find any acoustic events that we were able to identify as Risso's dolphin.

Vocal elements comprising detected dolphin vocalizations were more diverse than those of beaked whales. In all datasets, most dolphin detections were identified as mixed. Mixed vocalizations simultaneously contained clicks and whistles, clicks and buzzing or a combination of all three. In the June HARP dataset all vocalizations were classified as mixed. The dolphin vocalizations in June SCORE B data were comprised of 45% mixed, 41% clicks and 14% whistles.

In the November datasets, vocal elements of detected dolphin vocalizations was distributed as follows: 61% mixed, 38.5% clicks and 0.5% whistles in HARP data; 57% mixed, 18% clicks and 25% whistles in SCORE A data; 82% mixed, 15% clicks and 3% whistles in SCORE B data; 82% mixed, 9% clicks and 9% whistles in SCORE C data. Vocal activity of dolphins exhibited clear diel variability, with the majority of vocalizations occurring during the night.

1. Seasonal differences

In the June time period dolphin vocalization detections made up 39% and 23% of all marine mammal detections for HARP and SCORE B datasets, respectively. These rates were even higher for November time period: 76, 84, 69 and 58% for HARP, SCORE A, SCORE B, and SCORE C datasets, respectively.

It is difficult to relate the observed seasonal difference in dolphin detections in this research to the established patterns of dolphin presence in the Southern California Bight for three reasons: First, there were only four events that we identified specifically as Pacific white-sided dolphin, and different delphinid species can exhibit different seasonal patterns. Secondly, the dolphin distribution in the Southern California Bight changes from season to season depending on ocean conditions and prey availability, with a more homogenous distribution during summer/fall (Hildebrand 2009). Lastly, the analyzed November data covered five days compared to the two days in June, thus increasing the chances of dolphin presence/detection in this area in November.

2. Spatial Differences

In the June 2008 data, we detected three acoustic events in each of the HARP and SCORE B datasets. Most HARP detections were comprised of mixed vocalizations, whereas SCORE B detections consisted of either clicks or whistles only. All detected events were short, not exceeding 42 min. There were no instances in which two hydrophones recorded conspecifics at the same time.

In the November 2008 data, HARP and SCORE A, B, C recorded 11, 14, 11, and 8 dolphin vocalizations, respectively. In six instances, conspecific animals were detected on at least two instruments concurrently. SCORE hydrophones detected the longest dolphin events (500 min by SCORE B and 322 min by SCORE C). Most mixed vocalizations and all whistles were detected in SCORE data with HARP detections being comprised of either mixed or clicks only. There was no significant difference in spatial distribution of detections between datasets from different SCORE hydrophones.

C. SPERM WHALES

We did not find any sperm whale vocalizations for the 13–15 June time period in either HARP or SCORE B datasets. In November data, most detected sperm whale vocalizations were categorized as clicks, although a single case of buzzing was detected in SCORE B.

SCORE C hydrophones did not have any sperm whale detections in November. However, there were unidentified sound detections in SCORE C at the same time period when concurrent detections were made on other hydrophones. We hypothesize, due to our conservative approach in marine mammal identifying; it would be consistent that these unidentified sounds could be sperm whale vocalizations.

1. Seasonal differences

In the November time period, about 19% of all marine mammal detections in HARP data were identified as sperm whale vocalizations. These rates were equal to 10, 19, and 28% for SCORE A, SCORE B, and SCORE C datasets, respectively.

We attribute the temporal variability to the difference in length between June and November datasets and to the fact that sperm whales are seasonal migrants through the Southern California Bight (Dohl 1980).

2. Spatial differences

In the November 2008 data, no sperm whale detections were made in SCORE C data. HARP, SCORE A and B recorded 2, 3 and 5 sperm whale events, respectively. In two instances, all three instruments recorded vocalizations of conspecific animals. This high rate of concurrent detections of conspecific whales can be explained by high source level of sperm whale sounds, which can be detected at distances of several tens of kilometers (Barlow and Taylor, 2005; Mellinger at al., 2007).

D. ANTHROPOGENIC

A single detection of ship noise was made in each of the HARP and SCORE B datasets. These two events were close to one another. Seven ship detections were made in November. Three of those detections were concurrent.

There was one echosounder detection in June and six in November. All echosounder detections were concurrent.

E. UNIDENTIFIED SOUNDS

In June 2008 unidentified sounds were detected only in SCORE B data. There were ten unidentified sound events found in SCORE B data.

In November 2008 dataset, approximately 2% and 4% of total detections remained unidentified in HARP and SCORE data, respectively. There were four instances where unidentified sounds were detected in HARP in SCORE datasets concurrently.

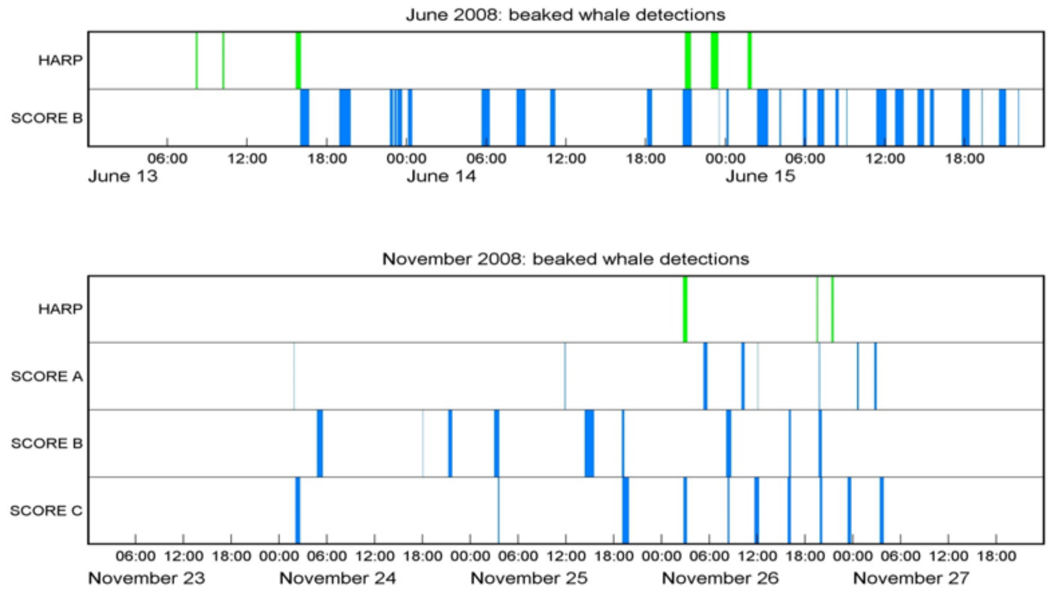


Figure 13. Occurrence diagram of beaked whale detections in June and November 2008 data. Green is for HARP detections and blue for SCORE A, B and C hydrophone detections.

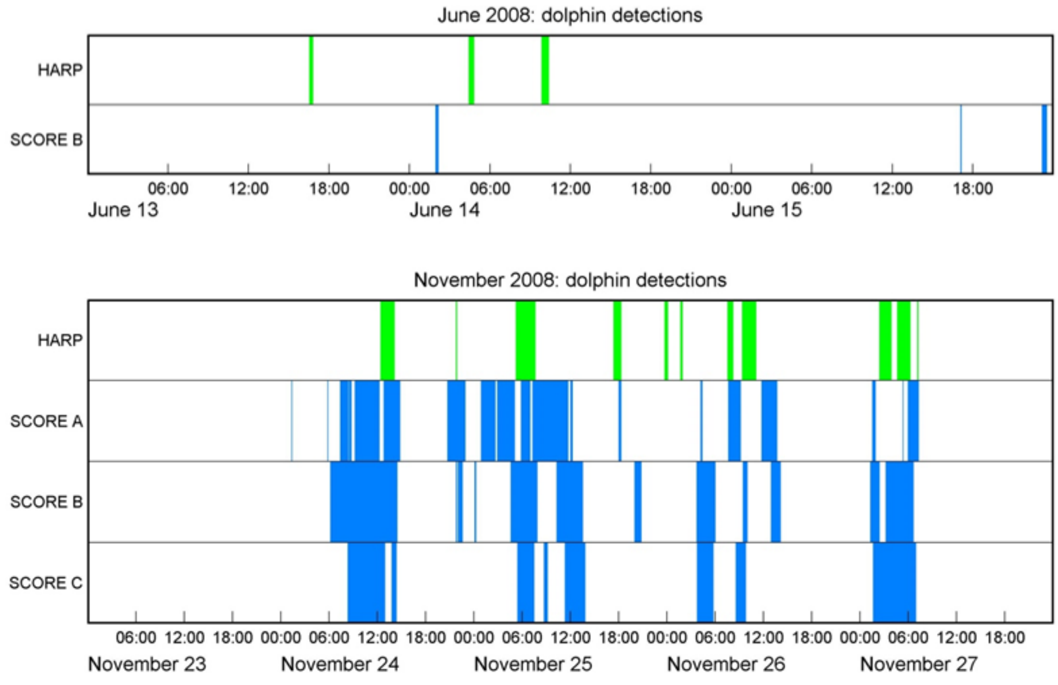


Figure 14. Occurrence diagram of dolphin detections in June and November 2008 data. Green is for HARP detections and blue for S CORE A, B and C hydrophone detections.

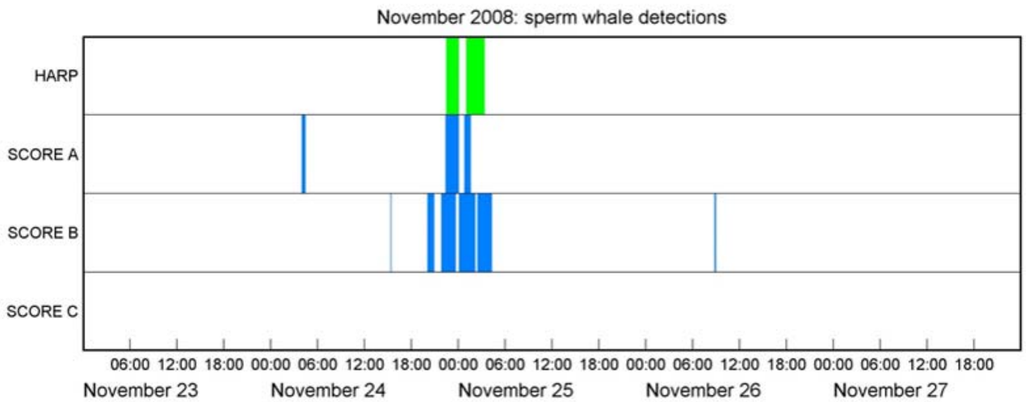


Figure 15. Occurrence diagram of sperm whale detections in June and November 2008 data. Green is for HARP detections and blue for SCORE A, B and C hydrophone detections.

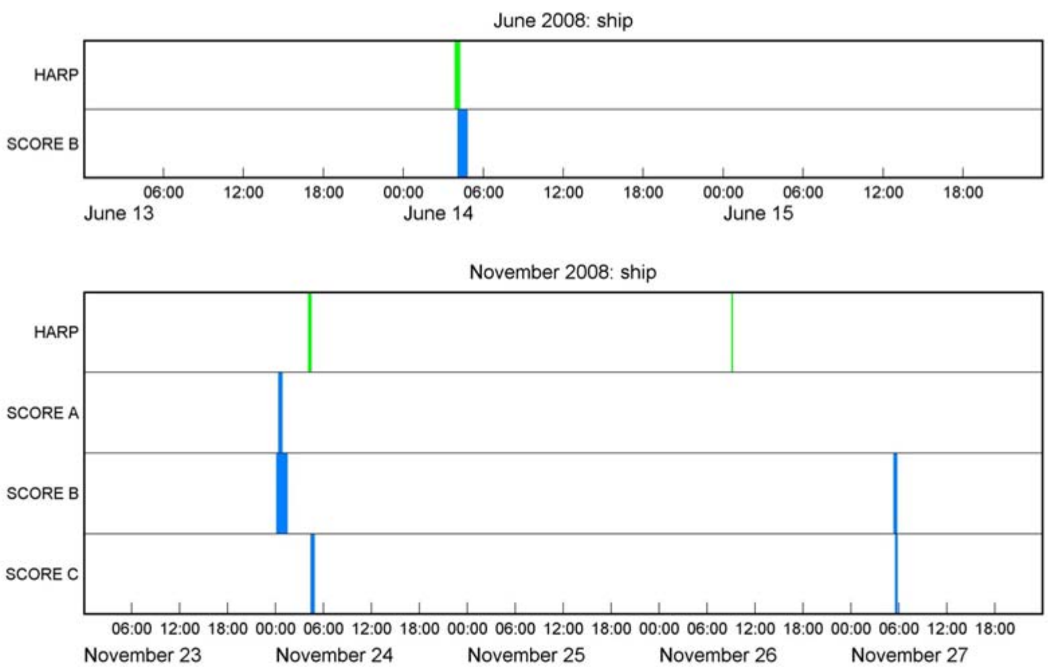


Figure 16. Occurrence diagram of ship detections in June and November 2008 data. Green is for HARP detections and blue for SCORE A, B and C hydrophone detections.

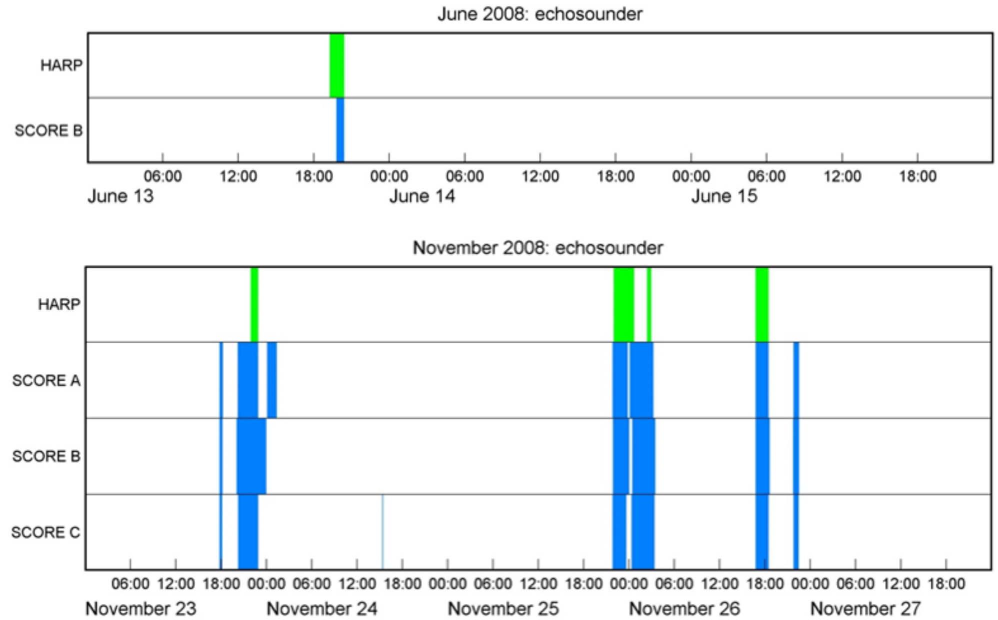


Figure 17. Occurrence diagram of echosounder detections in June and November 2008 data. Green is for HARP detections and blue for SCORE A, B and C hydrophone detections.

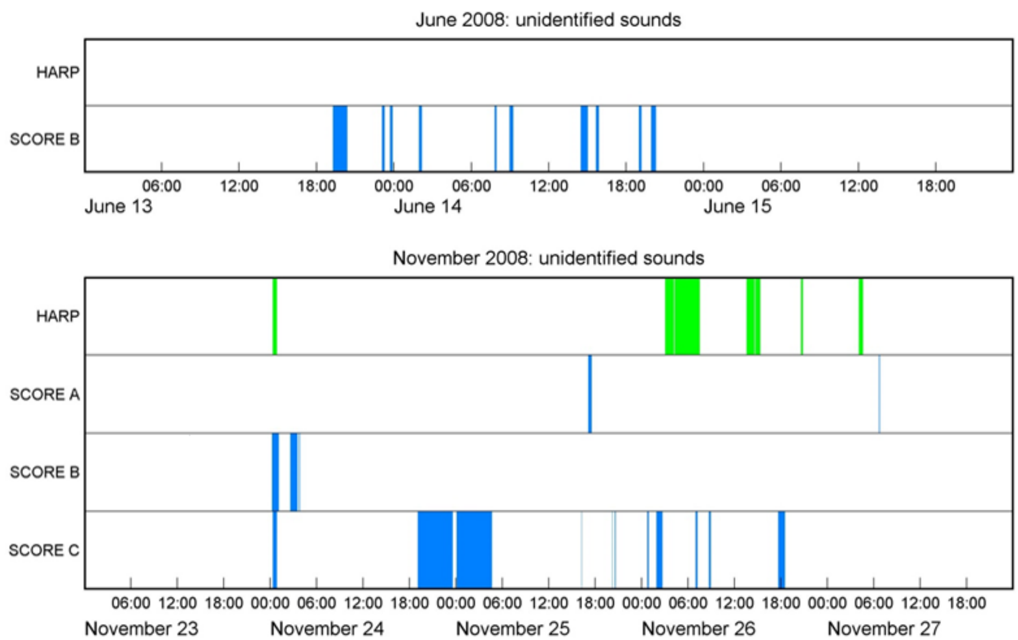


Figure 18. Occurrence diagram of unidentified sound detections in June and November 2008 data. Green is for HARP detections and blue for SCORE A, B and C hydrophone detections.

VI. DISCUSSION

We visually scanned 456 hours of data from two HARP deployments and three SCORE hydrophones collected from two different seasons over a period of eight days. As we summarize this research, we can categorize all of the information processed into three groups: what we anticipated, what we did not anticipate and what we learned.

A. WHAT WE ANTICIPATED

We detected and identified those odontocetes that vocalize in the frequency bands of interest and are known to be either transient or resident in the Southern California Bight area. We detected beaked whales, dolphins, and sperm whales. Four of the detected dolphin events were identified to species as Pacific white-sided dolphins. We did not find any unexpected marine mammals.

Dolphins are very talkative and boisterous animals that tend to travel in large numbers, sometimes in the thousands. Beaked whales tend to travel in small groups, from two to seven members, and produce echolocation clicks that are very directional. Due to these characteristics, we expected that we would find more dolphin than beaked whale detections. In this research, we found almost four times the amount of hours of dolphin detections as beaked whale detections.

Dolphins tend to feed at night and thus we expected to find the majority of dolphin echolocation clicks and buzzing to occur during this time. Dolphin detections found in this research exhibited a very pronounce diel variability.

The longer the event duration the more likely it would be recorded on more than one instrument concurrently. Comparing HARP and SCORE event occurrence between November (5 days) and June (2 days) (see Figure 14 for an example), we can see that the November data contained longer events and almost three times the amount of detections, which were attributed to conspecific animals.

We expected that the SCORE hydrophones that were closer in distance would have more concurrent detections of conspecific animals than those further apart. In this data, we saw that such detections from SCORE A/B and SCORE B/C, which were 10 and

4 km apart, respectively. There was only one event captured concurrently by SCORE A/C, which are 13 km apart. There were however, six events captured by all three SCORE hydrophones.

B. WHAT WE DID NOT EXPECT

SCORE hydrophones had a higher percentage of detections over the recording period than HARP (Table 2): in June, beaked whale detection rate was 18.6% and 3.7% in SCORE and HARP data, respectively; in November, these numbers were 4.2% vs. 1.2%. Possible reasons SCORE hydrophones captured more beaked whale detections than expected was due to the AGC feature these hydrophones are outfitted with, as well as location and the deeper depth of SCORE hydrophones. Further investigation is warranted.

November datasets had much more activity than June. As we went through the datasets, scanning and identification skills improved. We wanted to ensure that the reason June lacked detections was not due to human error, so we scanned June datasets twice: once in the beginning and for a second time after we had completed November's datasets. However, our second scanning of June data also indicated a sparse amount of marine mammal vocalizations present.

We also had three times the hours of November data than we had of June for this research. Although we understand that the shorter the data duration, the less representative of marine mammal behaviors it is, we were still surprised by the difference in the number of detections. We hypothesize that these differences are combined effect of seasonality in odontocete presence, patchiness of their distribution due to difference in environmental conditions (including prey availability) as well as limited duration of analyzed data sets.

We did not find any sperm whale detections in June but found 23 hours of sperm whale vocalizations in November. We attribute the temporal variability in the sperm whale detections to known randomness of year-around sperm whale presence in the Southern California Bight (Dohl 1980), and difference in length of June and November datasets.

We did not find any Risso's dolphin vocalizations in any of our datasets. Risso's dolphins are one of the two dolphin species that can be identified to species by the spectral content of their clicks. We surmise the reason we did not detect them was not because of the recording system's limitations but because they just were not physically present in close proximity to our instruments during the analyzed time periods.

SCORE had a higher percentage of unidentified sound detections per total detections in each dataset, 11 and 4% in June and November, respectively. We suspect that most of these unidentified sounds are marine mammal vocalizations and even think that they may have been distorted beaked whale clicks. However, because we chose a conservative approach to limit false positives in this research, we chose to "err on the side of caution" and leave these detections as unidentified.

C. WHAT WE LEARNED

Although we expected there would be performance differences between SCORE and HARP instruments, we also learned that each of the three SCORE hydrophones responded differently. SCORE A and B had sensitivity bands at different frequencies, whereas SCORE C had a flatter response than SCORE A or B. These differences produce slightly different characteristics of the displayed signal.

We were also able to list the features of beaked whale and Pacific white-sided dolphin echolocation clicks as presented in SCORE data. Received beaked whale clicks were affected in two major ways. There was a flattening of the characteristic upsweep due both to hydrophone filtering and using a Nyquist frequency near the peak frequency. The second way is that the click spectra were also altered by narrowing the spectral peak bandwidth and shifting the peak frequency. However, ICI and click duration maintained the same characteristics as published results.

The Pacific white-sided dolphin presented the signature alternating high and low amplitude bands in the spectrograms at the frequencies associated with PWSD. However, the first spectral peak of the two PWSD acoustic events recorded by SCORE A and B detections were elevated by receiver sensitivity bands that are present in these hydrophones. This is discussed in more details below.

1. Individual Instrument Characteristics and their Effects

This section summarizes each instrument's dataset by plotting the whole record on a single LTSA, and discusses the apparent peculiarities of instruments and how results of marine mammal detection/identification were affected by these characteristics. Figures 19-24 show LTSAs for individual datasets. In order to provide a figure in which acoustic events were easily distinguished we adjusted contrast and brightness of each figure as it is typically done in Triton. Figure 25 shows mean spectral content of each datasets, which was calculated by averaging corresponding LTSAs over the total length of each dataset.

a. HARP

The HARP LTSA for June is shown in Figure 19. There was unidentified noise present throughout the dataset in 24 to 31 kHz frequency band with several pronounced harmonics at approximately 27 and 28 kHz. The noise is represented by the bright yellow bands on the LTSA. This noise made it difficult to visually detect acoustic events at these frequencies because the intensities of the noise masked the most important feature of marine mammal vocalizations. The power spectra curve (Figure 25) for June shows a combined effect of the noise and marine mammal vocalization in 25-35 kHz frequency band.

HARP LTSA for November is show in Figure 20. The LTSA shows the data lacked both distracting background noise and marine mammal vocalizations. The corresponding power spectra curve (Figure 25) is relatively flat and does not display pronounced maximums or minimums.

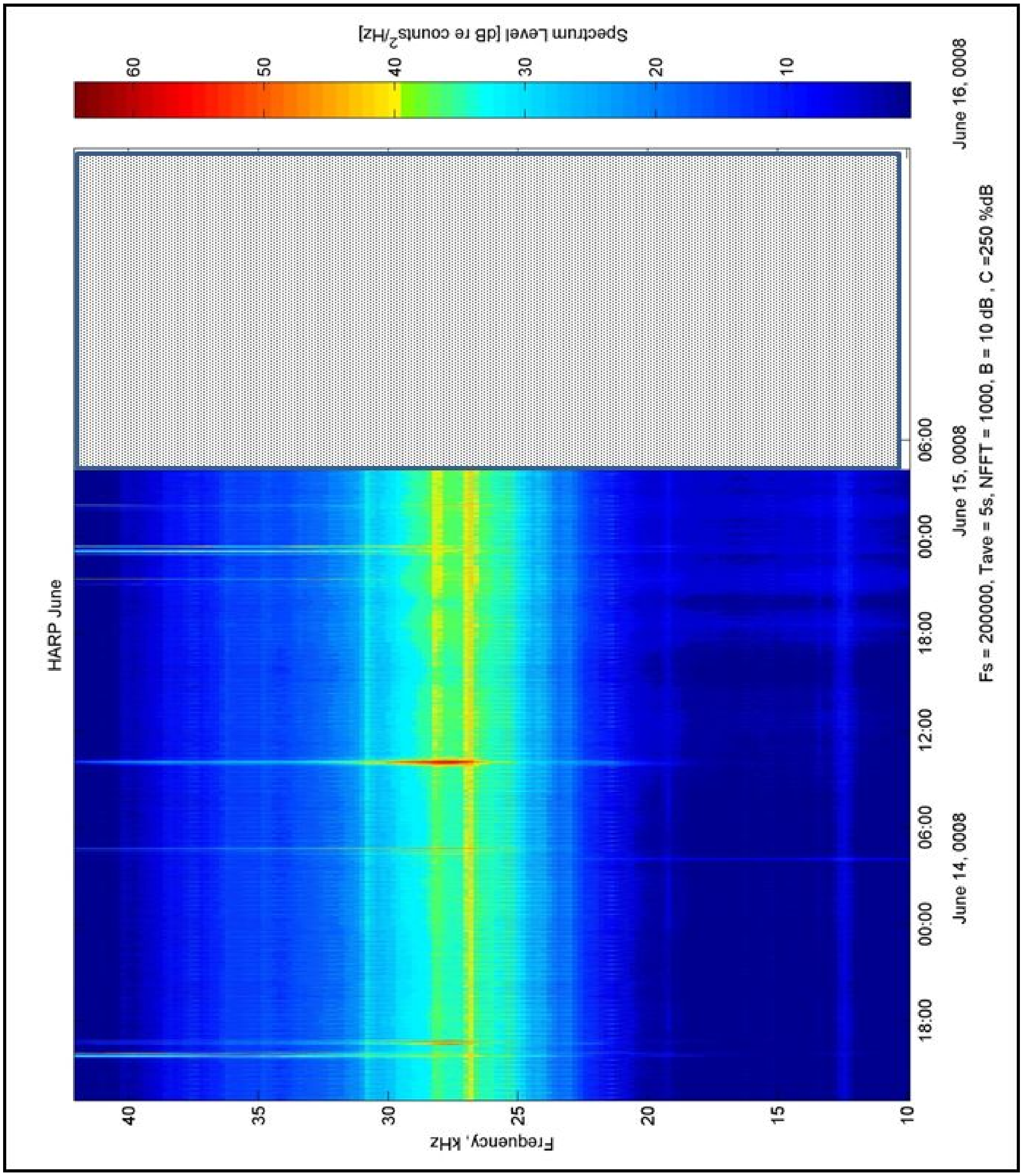


Figure 19. HARP LTSA for June 2008. The LTSA parameters are shown by the legend located in the right lower corner of the spectrogram.

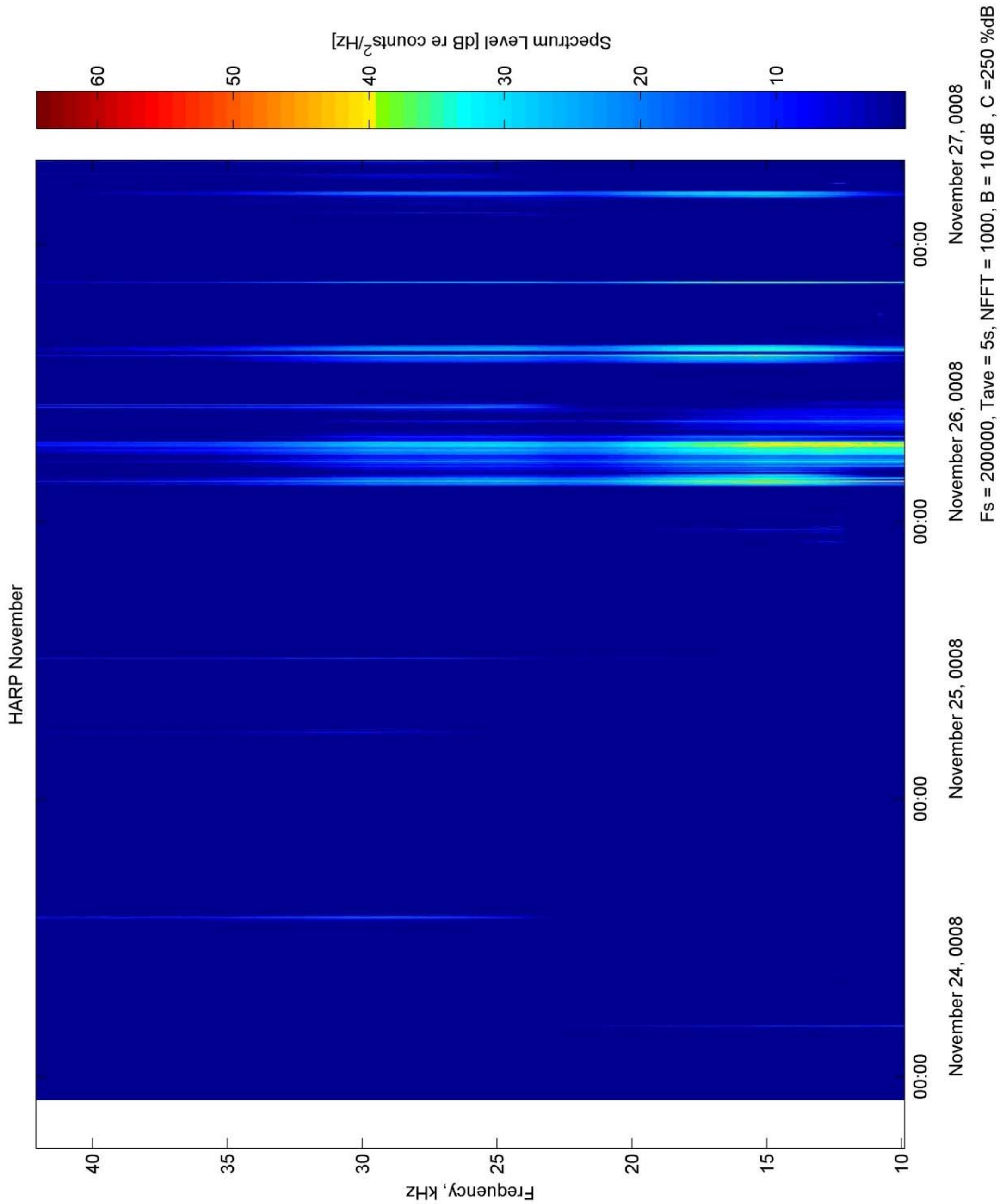


Figure 20. HARP LTSA for November 2008. The LTSA parameters are shown by the legend located in the right lower corner of the spectrogram.

b. SCORE A

SCORE A LTSA for November, 2008 has a band of elevated intensity that spans from approximately 22 kHz to 29 kHz. We hypothesized that this band is a combined result of two effects: enhanced sensitivity of the hydrophone and odontocete clicks present in this frequency band. In turn, this may affect results of data scanning. This sensitivity band, seen as a light blue band around 25 kHz, could make it easier to visually detect marine mammal vocalizations in the LTSAs. However, it could make identification of marine mammal vocalizations more difficult by shifting how peak intensity values are displayed. The effects of this sensitivity band are discussed in more detail when we discuss beaked whale and PWSD click features below.

The power spectra curve (Figure 25) for SCORE A has three peaks. The first peak occurs at 10 kHz. We speculate that this peak happens because of the acoustic events that occur in the bins between 10 and 15 kHz. The second peak occurs at approximately 23 kHz. We hypothesize the reason for this peak is the instrument's sensitivity band amplifying the marine mammal vocalizations present. The third peak occurs at 38 kHz. We suspect this peak is formed due to the filter that suppresses frequencies above 40 kHz.

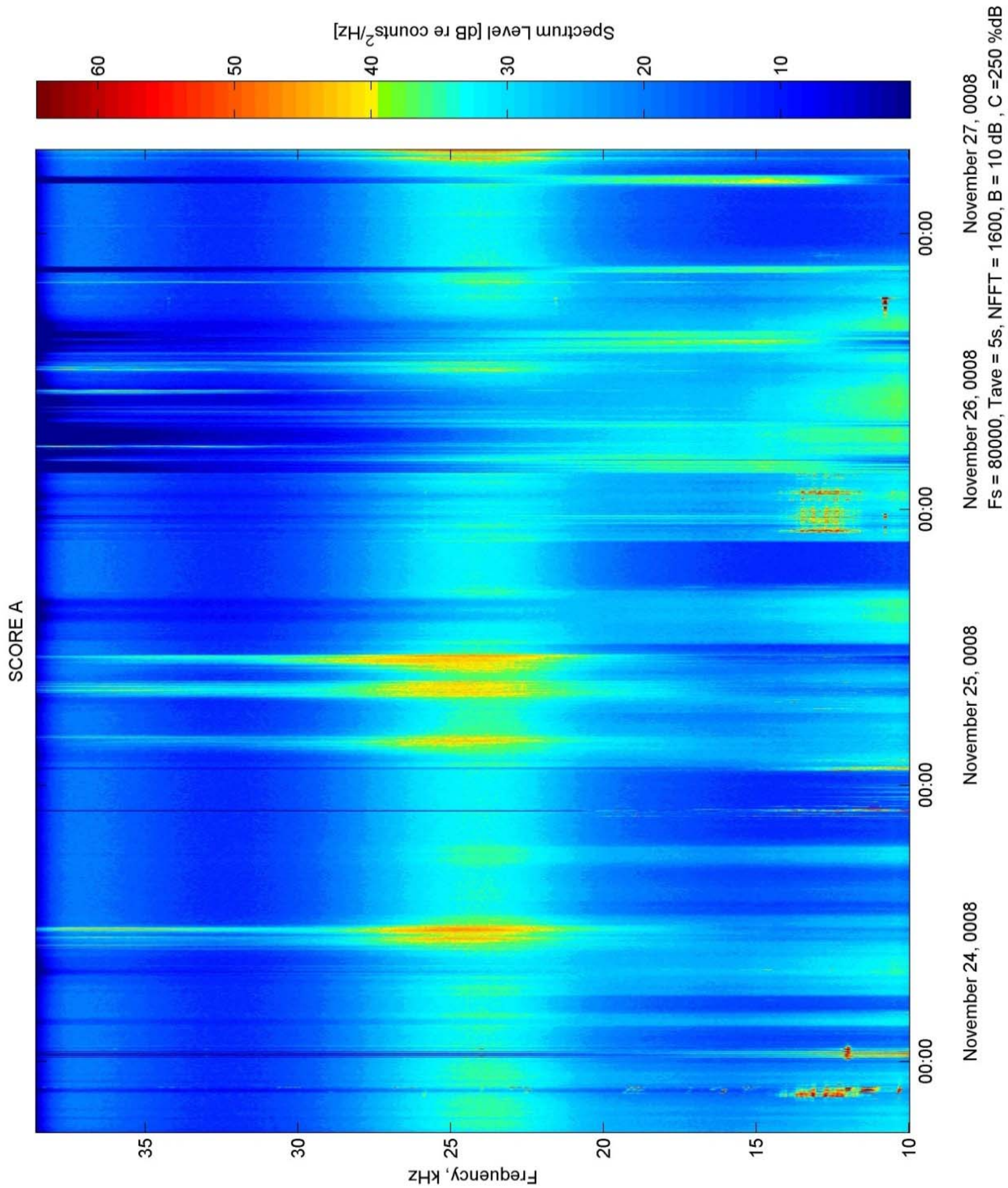


Figure 21. SCORE A LTSA for November 2008. The LTSA parameters are shown by the legend located in the right lower corner of the spectrogram.

c. SCORE B

SCORE B instrument appears to have a sensitivity band that spans from approximately 22 kHz to 24 kHz (Figures 22 and 23). As with SCORE A, this sensitivity band, seen as a light blue band between 20 and 25 kHz, could make it easier to detect

marine mammal vocalizations near this frequency (in LTSAs). However, it could make identification of marine mammal vocalizations more difficult by shifting the displayed peak frequency value. This sensitivity band appears in the same place in both June and November LTSAs.

The power spectra curve (Figure 25) for November SCORE B datasets also has three peaks. The first peak occurs at 10 kHz. We suspect this peak occurs due to high intensity acoustic events that occurred on the 24 and 26 of November (seen as the dark red forms on Figure 23) and because of the broadband filter that suppresses frequencies below 10 kHz. The second peak occurs at approximately 22 kHz. We suspect the reason for this peak is the instrument's sensitivity band amplifying the marine mammal vocalizations present. The third peak occurs at 38 kHz. We suspect this peak occurs due to the broadband filter that suppresses frequencies above 40 kHz.

June SCORE B power spectra curve has relatively the same shape, but the overall intensity values are much lower due to less events overall and the sampling frequency. The three peaks occur at the same frequencies as November SCORE B's. We speculate that the first and third peaks of the spectra are caused by the broadband filter for frequencies below 10 kHz and above 40 kHz. The second peak also occurs at approximately 22 kHz. We suspect the reason for this peak is the instrument's sensitivity band amplifying the marine mammal vocalizations present.

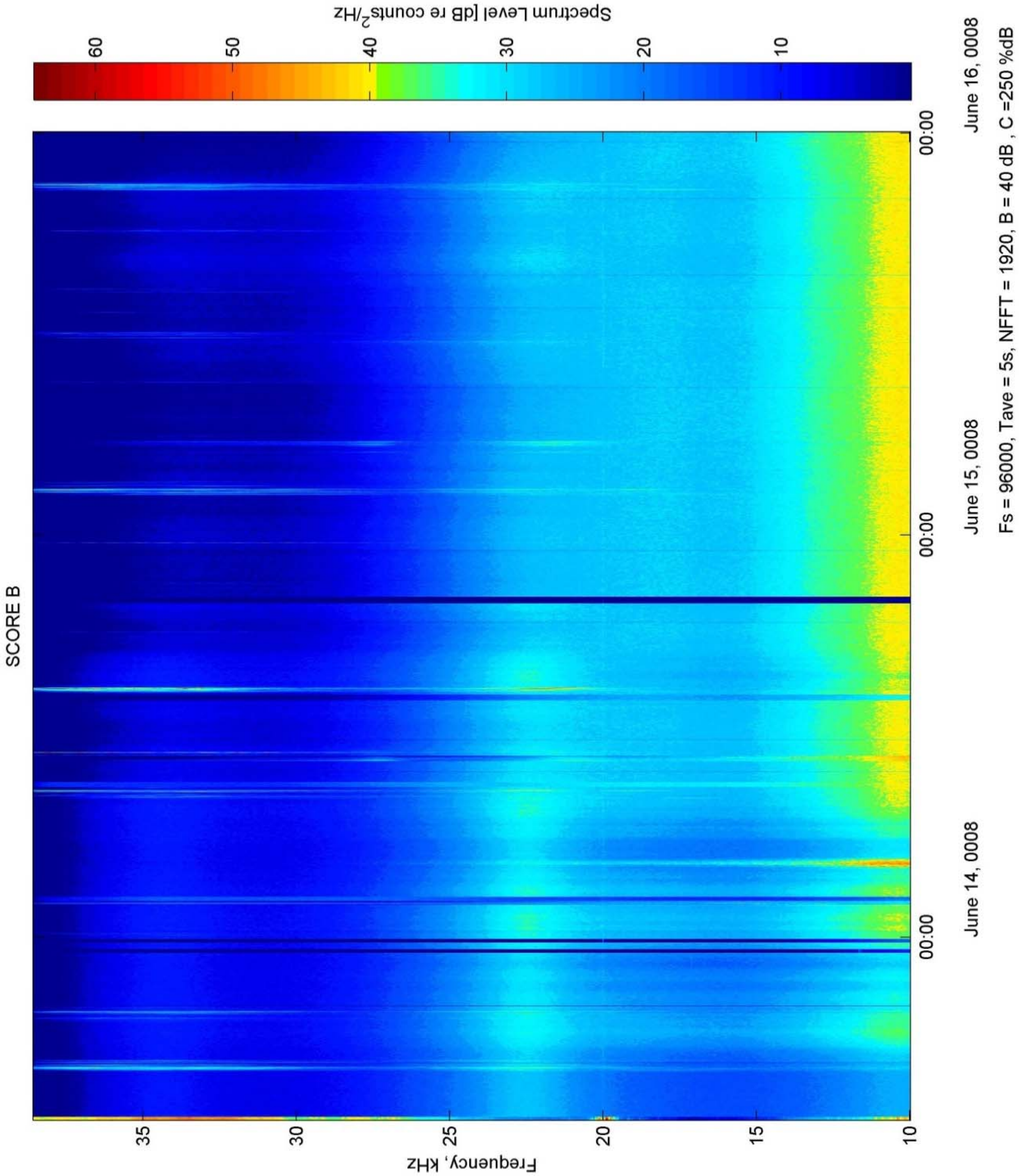


Figure 22. SCORE B LTSA for June 2008. The LTSA parameters are shown by the legend located in the right lower corner of the spectrogram.

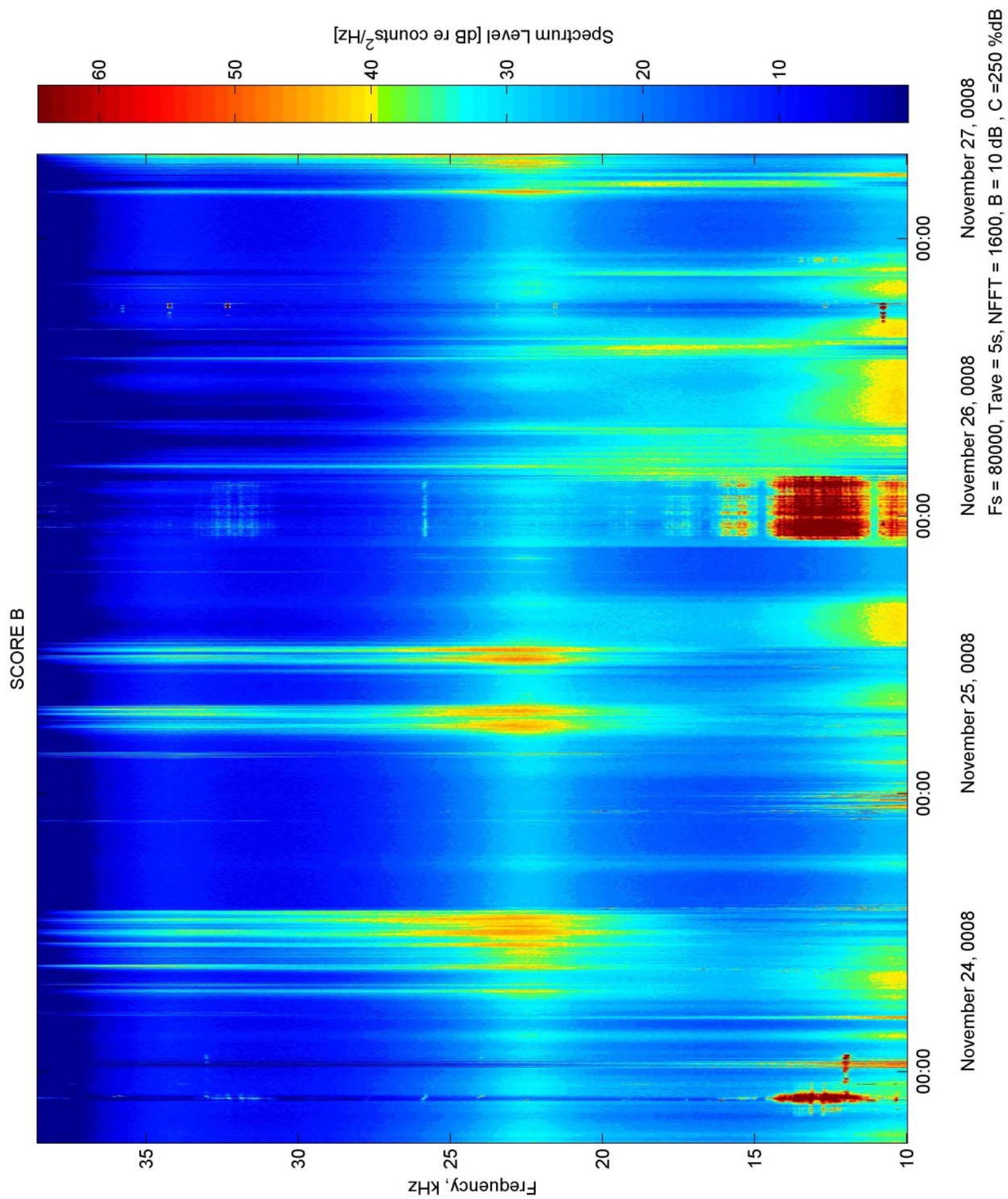


Figure 23. SCORE B LTSA for November 2008. The LTSA parameters are shown by the legend located in the right lower corner of the spectrogram.

d. SCORE C

SCORE C was the only hydrophone that did not have a sensitivity band (Figure 24). No vocalizations were intensified due to sensitivity issues as discussed above in SCORE A and B.

The power spectra curve for SCORE C had only two peaks (Figure 25), which are less pronounced than those for two other hydrophones. The first peak occurs at approximately 8 kHz. We speculate that reason for this first peak is the acoustic event that occurred on 26 November (Figure 24). The second peak occurs at 38 kHz. We suspect this peak occurs due to the filter that suppresses frequencies above 40 kHz.

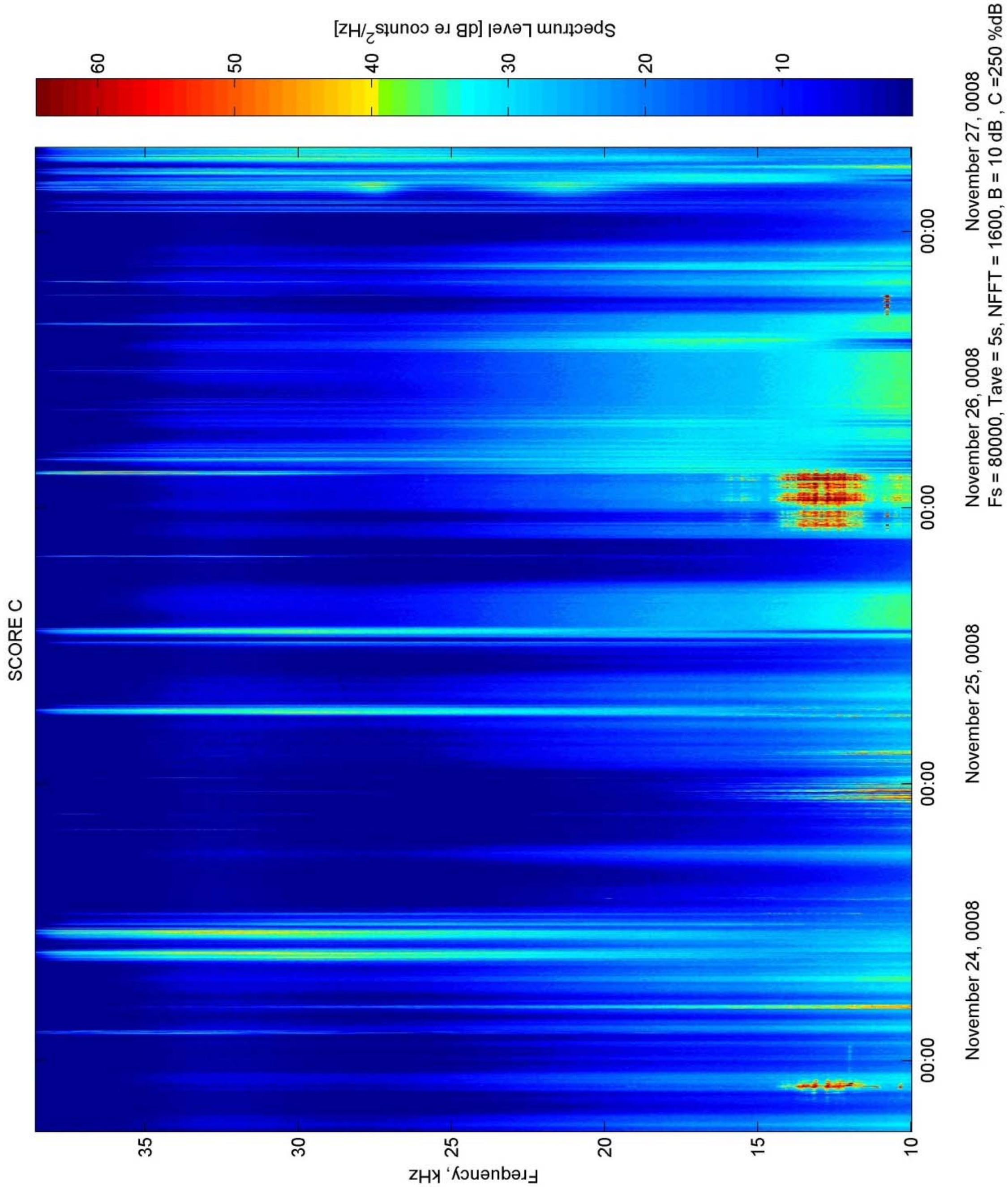


Figure 24. SCORE C LTSA for 23-27 November 2008. The LTSA parameters are shown by the legend located on the right side of the spectrogram.

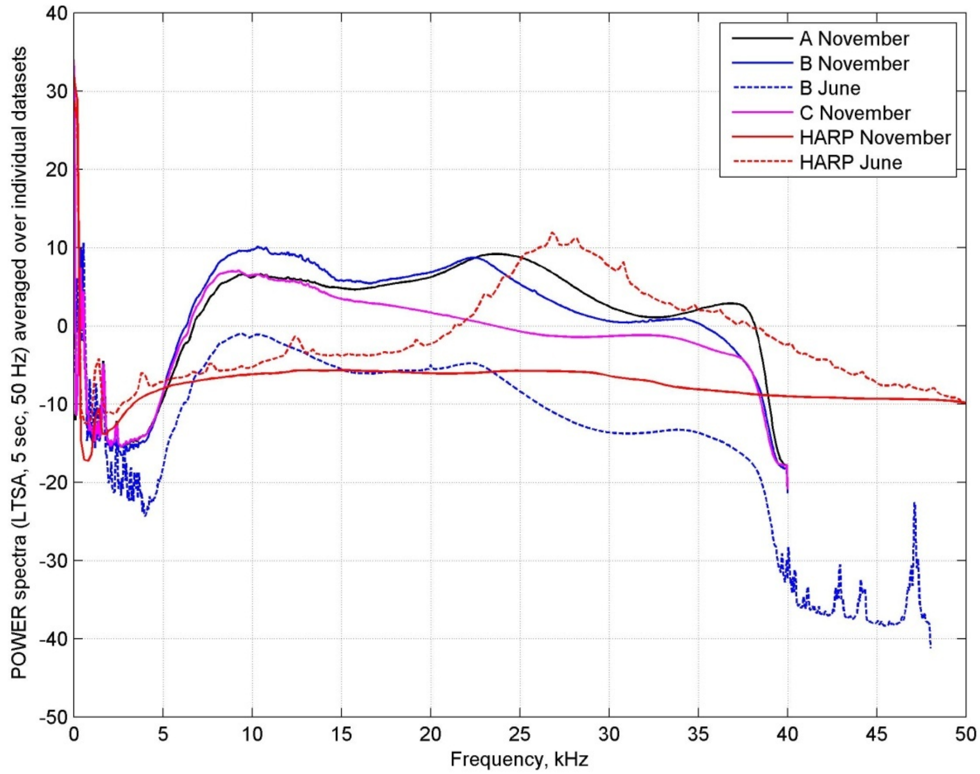


Figure 25. Mean spectral content by instrument and season. The power spectra curves were calculated by averaging corresponding LTSAs over individual datasets.

2. Characteristics of Marine Mammals' Vocalizations Recorded by SCORE Instruments

In order to species-level identify marine mammal vocalization acoustically, it is important to establish invariant and distinctive features of their vocal elements. Vocalization features already established for certain marine mammals on one recording system may appear modified due to specific operating characteristics of another system. This section describes beaked whale and Pacific white-sided dolphin click characteristics as presented in SCORE data.

Cuvier's beaked whales and PWSD dolphins are the two odontocetes found in our datasets that have published click features. Beaked whale clicks are identified by an inter-click interval of ~0.4 s, an upsweep in frequency from 20 to 60 kHz with the peak frequency at 40 kHz, click duration of at least 200 μs and a deep notch at approximately

26 kHz in the spectra (Zimmer 2011). PWSDs are identifiable to species by the presence of four characteristic spectral peaks at 22.2, 26.6, 33.7 and 37.3 kHz and three characteristic spectral notches at 19, 24.5 and 29.7 kHz (Soldevilla et al. 2008) in their clicks.

The examples discussed in this section are not meant to be representative of the species as a whole or even a specific population. Due to the limited amount of data used in this research, click samples taken from an individual dataset for a certain species, are most likely produced by several animals (or a group of animals) at most. Thus the examples in this section certainly may contain characteristics of individual animals. However, this approach allows us to answer two important questions. How are distinctive features presented in SCORE data and do the features still allow us to identify specific species? How are these vocalization features distorted by the SCORE recoding system?

a. Beaked Whale

1. Interclick interval To estimate the interclick interval from SCORE dataset, we drew approximately 100 clicks from each dataset and calculated a sample median and its interquartile range. As seen from the box plot for different dataset (Figure 26), ICI values for both HARP and SCORE data fit primary within the 0.3-0.6 s range, which is a known robust feature of Cuvier's beaked whale (Zimmer et al. 2005).

HARP June data had higher variance in ICI length whereas HARP November had the least variance. SCORE A's sample median was the closest to the 0.4 s. SCORE B June had most outliers, which were ICI lengths calculated to be 1.5 times the interquartile range away from the top or bottom of the box. SCORE B November and SCORE C November had closest ICI interquartile values of all the data sets.

Note that most outliers lie above the top of the box but none are lower than 0.25 s. It is known that beaked whale sometimes cease their click sequences for longer than 1 s, and thus higher ICI values are possible when averaged over the click

train (Zimmer et al. 2005), while ICI less than 0.2 s would raise suspicion that the vocalization was not produced by a beaked whale.

Caution should be taken however when interpreting the above statistics as they can be highly biased by representing individual characteristics of several individual whales in each dataset but not the species/population as a whole. Nevertheless, we can conclude that the mean interclick interval value of 0.43±0.092s (Zimmer et al. 2005) is still a highly robust feature of Cuvier's beaked whale clicks as recorded by SCORE instruments, and can be used to distinguish these animals from other odontocete species.

2. Duration and spectral content of an echolocation click

Beaked whale clicks are very directional, so clicks that are not received by the hydrophone on-axis can become distorted and suffer transmission loss (Zimmer et al. 2005). The criteria for choosing a click was it had to be somewhat in the middle of the click train and have a strong signal. We selected one click from both SCORE B and SCORE C data to see how sampling frequency and an existence of sensitivity bands would affect clicks. SCORE B data were recorded at a sampling frequency of 96 kHz and has a sensitively band along the 22 to 24 kHz frequency range. SCORE C data was recorded at a sampling frequency of 80 kHz and lacked a sensitivity band. Note both hydrophones are equipped with a filter that suppresses signal above 40 kHz.

Spectrograms, time series and power spectral density estimates of a beaked whale clicks found in SCORE B and SCORE C datasets were plotted to analyze how click length, upsweep and spectral content of beaked whale clicks were affected by the individual hydrophone characteristics (Figures 27 and 28).

Spectrograms of individual clicks were calculated from recording clips of 0.1 s length using a Hanning window and FFT with 32 samples and 31 samples of overlap, and plotted in upper panels of Figures 27 and 28 for June SCORE B and November SCORE C datasets, respectively. Two features were examined using these spectrograms: the shape and bandwidth of the clicks upsweep feature and the value of the peak frequency.

The SCORE B spectrogram has a distinctive upsweep in frequency that is typical of a beaked whale echolocation click, which goes from 20 to 60+ kHz over a 0.15 µs interval (Zimmer 2011). We hypothesize that the upsweep feature has been slightly flattened by the SCORE hydrophone filter that suppresses signals above of 40 kHz reducing the signal received from the higher-frequency part of the beaked whale click (i.e., from 40 to about 60 kHz).

The beaked whale click from SCORE C (Figure 28) also presents the upsweep feature but has been flattened even more so than the click from SCORE B (Figure 27). We hypothesize the reason behind the flattening of the spectrogram form is twofold. First the broadband filter applied to all SCORE hydrophones for frequencies above 40 kHz changed the shape as in SCORE B data. Secondly, SCORE C was set to record acoustic events at a sampling rate of 80 kHz in November. Since the Nyquist frequency was about the same as the filter some of the high-frequency portion of the beaked whale click was folded due to aliasing.

Beaked whale clicks are known to have duration of around 200 µs, whereas most dolphin clicks last between 20 and 100 µs (Zimmer et al. 2005). The time series of beaked whale clicks are shown in the bottom left panel of Figures 27 and 28 for June SCORE B and November SCORE C datasets, respectively.

The duration of beaked whale click found in SCORE was approximately 240 µs. In SCORE C the beaked whale click had duration of approximately 300 µs. In both cases the click duration parameter for beaked whale identification holds true, and can be used as a distinctive feature for identification of beaked whale echolocation clicks.

In order to be classified as a beaked whale echolocation click, a click should have a spectral bandwidth from 20 to 60 kHz with a peak at 40 kHz (Zimmer et al. 2005) and a pronounced (about 20 dB) spectral notch at about 26 kHz. Estimated Welch power spectral densities are shown in lower right panels of Figures 27 and 28 for June SCORE B and November SCORE C data, respectively.

The beaked whale click from SCORE B has spectral bandwidth from about 31 to 38 kHz and a spectral peak around 35 kHz (Figure 27). The spectral

bandwidth is narrower and the peak frequency has been shifted downwards by about 5 kHz as compared to corresponding published features. The spectral notch is present at approximately 26 kHz but it is rather shallow (about 7 dB). We suspect the narrowing and shifting of peak frequencies are caused by the filtering above 40 kHz applied to all SCORE hydrophones. We speculate the reason the spectral notch is more shallow than expected is due to the sensitivity band found in SCORE B hydrophone. Although this notch is not as deep as in the 2005 research of Zimmer et al., the spectra still maintain relatively the same shape. If the properties of a sensitivity band are known prior to scanning and identification efforts, the spectral density plot can still be used for beaked whale identification.

SCORE C has a spectral bandwidth from about 31 to 33 kHz and a spectral peak around 32 kHz (Figure 28). The spectral bandwidth is even narrower and more downwardly shifted than that of SCORE B. Here we suspect the narrowing and shifting of frequencies is due to the same reasons the upsweep in the spectrogram was distorted: first because of the filter applied and second due to the 80 kHz sampling frequency causing aliasing of the high frequency part of the signal. The spectral notch that occurs around 26 kHz maintains the pronounced depression (about 20 dB). We hypothesize the reason the spectral notch was not changed because SCORE C hydrophone does not have a sensitivity band similar to SCORE A and B.

Published features of beaked whale click spectra include a spectral bandwidth from 20 to 60 kHz with the peak frequency around 40 kHz and about a 20 dB pronounced dip at 26 kHz. These features are still relevant in identifying beaked whale clicks in SCORE data with the caveat that the individual hydrophone characteristics must be taken into account. Due to the filtering of frequencies above 40 kHz and the presence of sensitivity bands in hydrophone response curves, the spectral bandwidth of peak frequencies will be narrower and the notch at 26 kHz may not be as pronounced. Low sampling rates that result in Nyquist frequencies near the peak frequency may also result in aliasing that further distort the appearance of the characteristic upsweep.

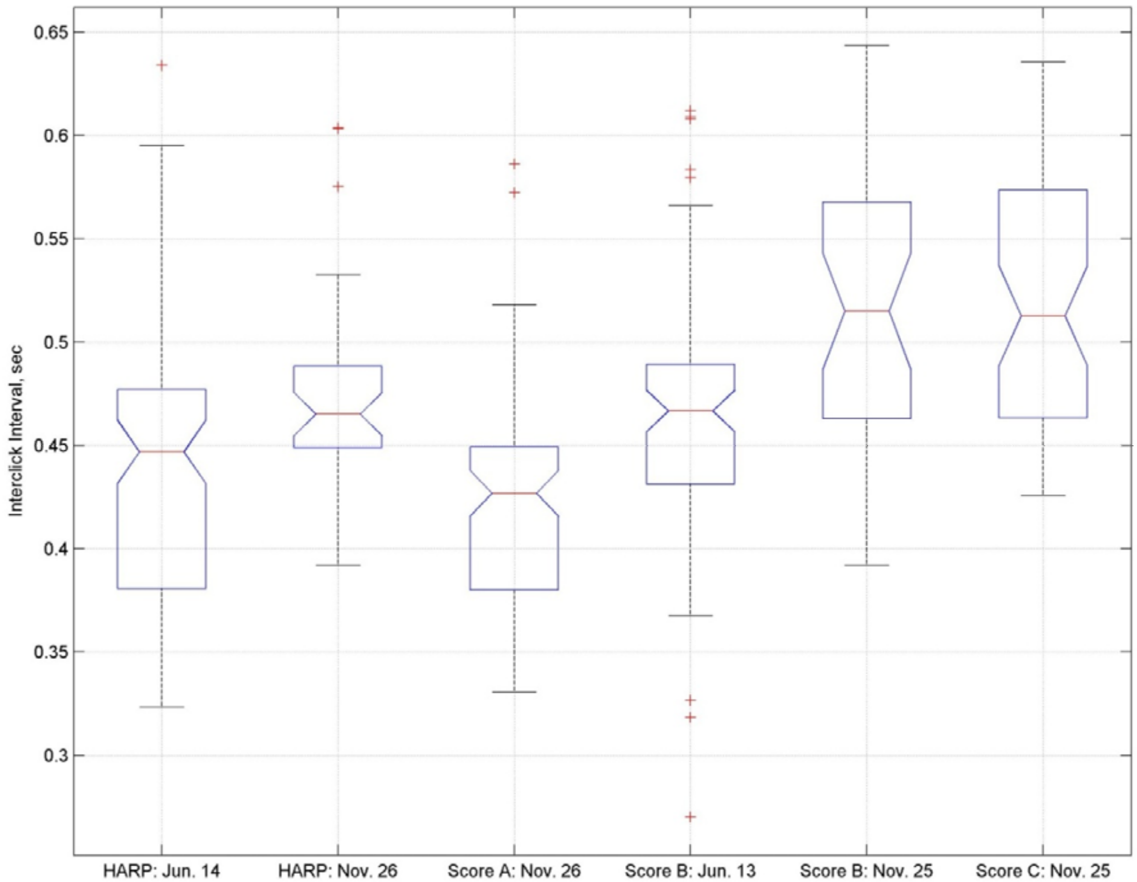


Figure 26. Beaked whale inter click interval box plot. Each box plot represents approximately 100 clicks randomly acquired from each dataset. The red horizontal line depicts the sample median. The red +s represent outliers. The top and bottom of the boxes are plotted at 25% and 75% quantiles. Whiskers are the lowest and highest values of ICIs in the datasets. Datasets from which the samples were drawn are shown along the x-axis.

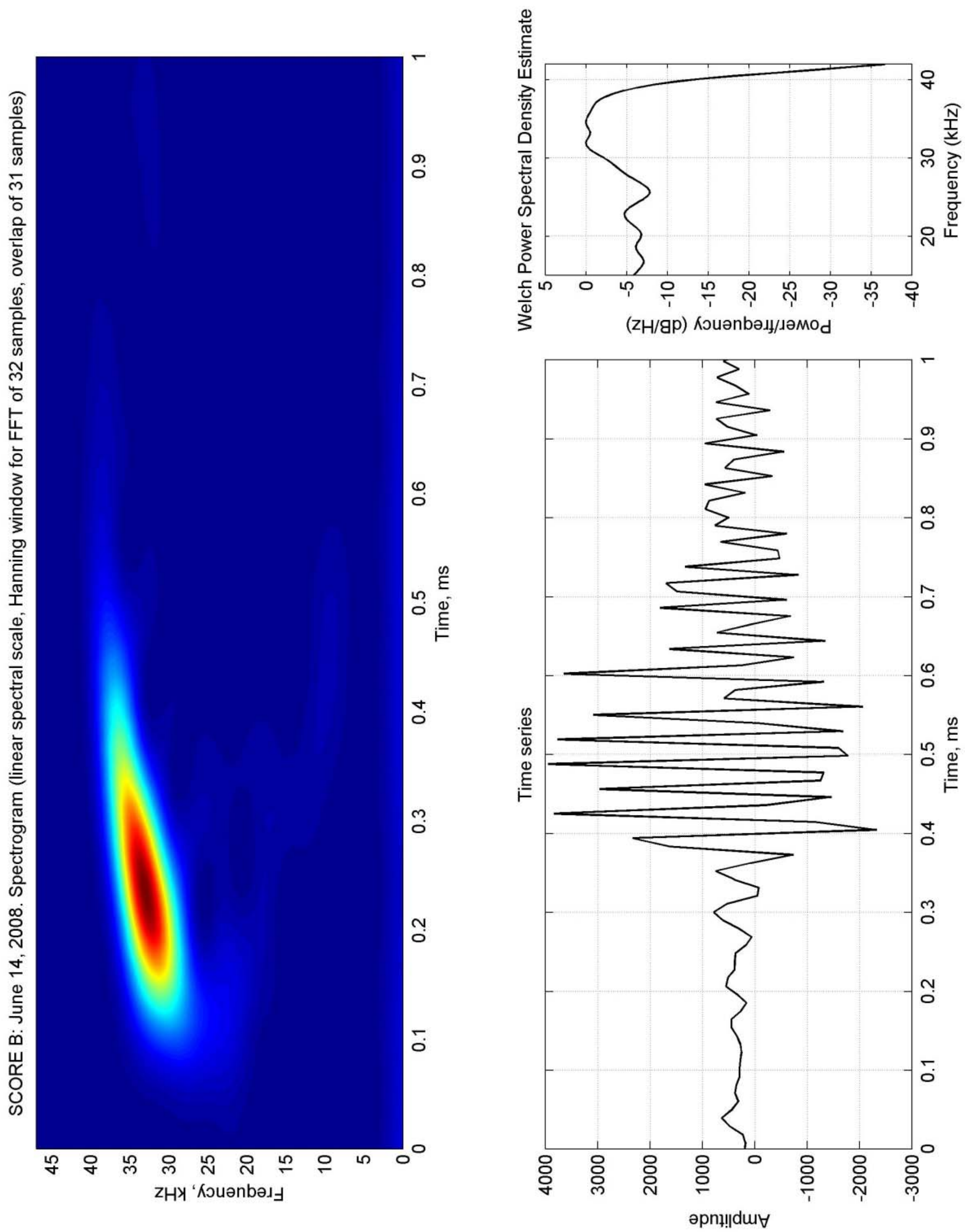


Figure 27. Spectral content and time series of a beaked whale echolocation click as recorded by SCORE B instrument on June 14, 2008. The top panel is the spectrogram calculated using Hanning window for FFT of 32 samples and overlap of 31 samples, and shown in linear scale. The bottom left panel shows the time series. The bottom right panel shows the Welsh power spectral density estimate.

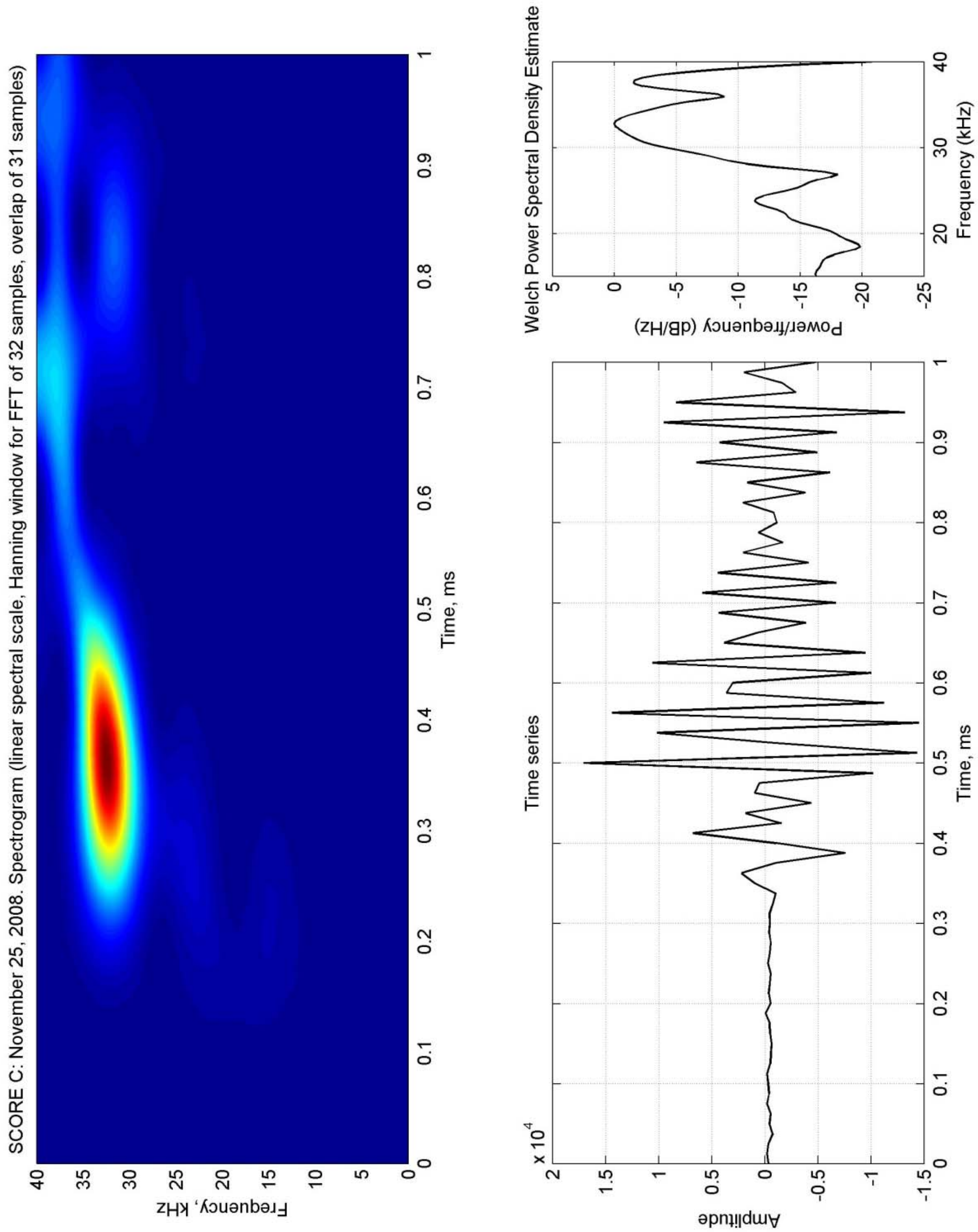


Figure 28. Spectral content and time series of a beaked whale echolocation click as recorded by SCORE B instrument on November 25, 2008. The top panel is the spectrogram calculated using Hanning window for FFT of 32 samples and overlap of 31 samples, and shown in linear scale. The bottom left panel shows the time series. The bottom right panel shows the Welsh power spectral density estimate.

b. *Pacific White-Sided Dolphin*

Pacific white-sided and Risso's dolphins are the only two delphinid species which are presently known to produce echolocation clicks with robust spectral peaks and notches that can be used for their identification on species-level. Values of the peak and notch frequencies have been established for free-ranging Pacific white-sided dolphins typical for Southern California region (Soldevilla et al. 2008). We found a total of four PWSD events in our datasets. Two events were recorded on SCORE B on 14 and 15 June, one event on HARP on 25 November and one event on SCORE C on 27 November (Figure 29). Each PWSD event had a different duration, with the event recorded by SCORE C lasting the longest.

The click patterns in these spectrograms show the alternating high and low amplitude bands that are evident at the frequencies associated with PWSD (Soldevilla et al. 2008). We compared only the first three peaks and the first two notch values because the filtering of the SCORE data above 40 kHz suppressed the other peaks and notches. The patterns are consistent for all four events, although intensity levels differ, on each of the different instruments.

Figure 30 shows the mean spectral plots averaged over the duration of each event and normalized for comparison purposes. From these data, mean values of peak and notch frequencies within 10–40 kHz frequency band were estimated for each event. Corresponding mean spectral curves (see Figure 25) were also normalized and superimposed onto each plot in Figure 30 to analyze how different hydrophone responses affected the peaks and notches of PWSD echolocation clicks.

The 14 June PWSD event on SCORE B had peak frequency values at 21.4, 27.4 and 32.2 kHz and notch frequency values of 19.3 and 26.3 (Table 3). We surmise that SCORE B's enhanced sensitivity in the frequencies between 22 and 24 kHz elevated the first spectral peak of the PWSD vocalization (Figure 30).

The 15 June event on SCORE B had peak frequency values of 21.5, 27.4 and 26.3 kHz and notch frequency values of 16.7 and 26.3 kHz (Table 3). As in the

case of the 14 June PWSD event, we attribute the elevation of the first spectral peak to the enhanced sensitivity of the SCORE B hydrophone.

The PWSD event recorded by HARP on 25 November had peak frequency values at 21.5, 27.5 and 31.5 kHz and a second notch frequency value of 25.4 kHz (Table 3). The fact that the first two peaks frequency values are close in amplitude follows the results of Soldevilla et al. (2008). This is due to the flat response of the HARP in the frequency band (Figure 30).

SCORE C's 27 November event had peak frequency values at 21.4, 27.5 and 32.1 kHz and a notch frequency value of 25.6 kHz (Table 3). These results also follow the results from Soldevilla et al. (2008) research and are due to the flat response of the SCORE C in the frequency band.

Table 3 summarizes the above peak and notch frequencies resolved in the 10 to 40 kHz frequency band in comparison with published results. The values for peaks two and three of PWSD events found in our data are consistant with the results of the the second and third peaks in Soldevilla et al. (2008) research, and imply that detected vocalizations were of Type B.

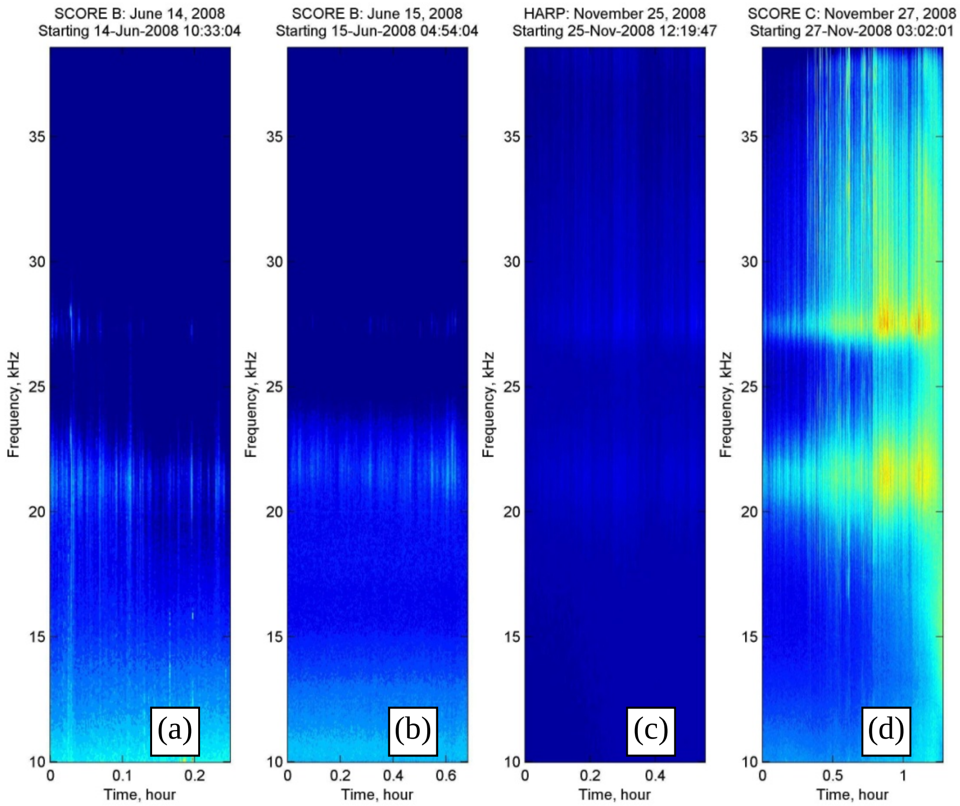


Figure 29. LTSAs of the four PWSD vocalization events in different datasets: (a) SCORE B on June 4, 2008 starting at 10:33am; (b) SCORE B on June 15, 2008 starting at 04:54 am; (c) HARP on November 25, 2008 starting at 12:19 pm; (d) SCORE C on November 27, 2008 starting at 03:02 am. The magnitude of the spectral content is represented by color. Red color represents the greatest concentration of energy whereas dark blue represents no or very little energy. Two consistent spectral peaks are evident in each LTSA.

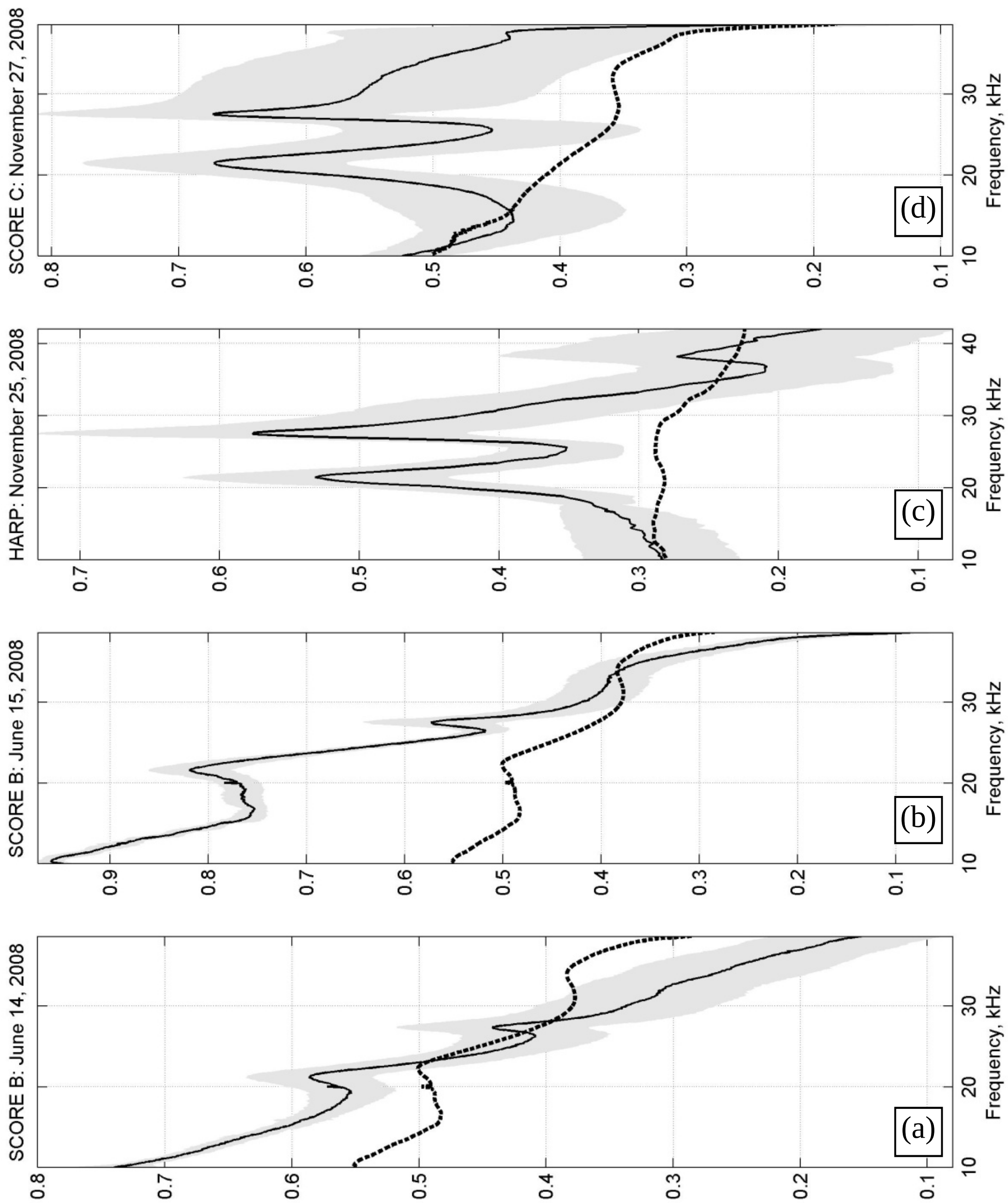


Figure 30. Normalized spectral content of PWSD echolocation clicks averaged over event duration for (a) SCORE B on June 4, 2008; (b) SCORE B on June 15, 2008; (c) HARP on November 25, 2008; (d) SCORE C on November 27, 2008. The gray shaded area is the standard deviation for each plot. Normalized mean spectral curve (averaged over each dataset duration) from Figure 25 has been superimposed onto each PWSD event's plot and is represented with a dotted line.

Table 3. Means of local peak and notch frequencies in kHz of PWSD echolocation clicks. Row one contains Soldevilla et al. 2008 means and standard deviations (in parenthesis) of peaks and notches for PWSD echolocation clicks Types A and B. Rows two through five contain the means for the four PWSD events we found in our datasets. These means were acquired from corresponding LTSAs over time.

	Peak 1	Peak 2	Peak 3	Notch 1	Notch 2
Soldevilla 2008: Type B Type A	 22.2 (0.6) 22.2	 26.6 (0.9) 27.4	 33.7 (1.4) 33.7	 19.0 (1.1) 19.0	 24.5 (0.9) 24.5
SCORE B June 14	21.4	27.4	32.2	19.3	26.3
SCORE B June 15	21.5	27.4	33.2	16.7	26.3
HARP Nov 15	21.5	27.5	31.5		25.4
SCORE C Nov 27	21.4	27.5	32.1	14.7	25.6

D. CONCLUSION

This research effort describes how a PAM system not designed to track marine mammals, such as SCORE hydrophones, performed as compared to a system designed detect marine mammal vocalizations.

Based on the results discussed in the above sections, we conclude that SCORE system can be used for passive acoustic monitoring of some odontocetes. In order to mitigate the effects that individual SCORE hydrophone characteristics may have on acoustic events, it is imperative that SCORE scanning protocols must be adjusted for hydrophone performance. Protocols must account for the way the broadband filter and lower sampling frequencies affect the upsweep and peak frequency of beaked whale clicks. Sensitivity bands for individual hydrophones must be identified and described in order to anticipate how spectra will be affected.

The next suggested step in this process is to automate the scanning and detection process. This will allow for large amounts of data to be more quickly analyzed. As it is now, scanning these large amounts of PAM data required intensive man hours.

A suggested way forward for automating this process is to construct a set of specific and invariant rules that replicate the human processing method. These rules

would allow a pattern recognition approach to be used to identify and extract species specific vocalization information from these very large datasets in a timely and efficient manner.

This information is valuable to the U.S. Navy for determining temporal and spatial distribution of marine mammals in and near naval training ranges. Understanding population distribution and its variability can improve understanding of marine mammals response to sounds generated from naval operations and exercises. This information can also lead to improved migration procedures that minimize the negative effects on marine mammals while maintaining fleet readiness.

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